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HELICOPTER DESIGN

by

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COUNTRY: USSR

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Foreword

The weight perfection of a helicopter, its reliability and the cost of its operation depend to a large degree on the level of design for its parts and their connections.

For parts, connecting pieces and assemblies of a helicopter, it is characteristic that vibrational loads act upon them. In connection with this, one of the basic tasks of the designer is that of finding wise means for increasing the fatique strength of these parts and their joints. The designer must be able to select the proper form for the part and junction, correctly distribute material, selecting means of transmitting and absorbing loads from one part to another and so forth.

In the design bureau, a large part of these tasks must be performed by the technician-mechanic. In connection with this, primary attention in this book is directed toward questions on the design of parts and their connections which are under the influence of changing loads.

The design of parts is organically tied with the process of designing components and sections of the helicopter. Therefore, the design of even the simplest parts cannot be undertaken without having a clear representation of their purpose and connection with neighboring parts and pieces. For the proper solution of the problems set before him, the technician-mechanic must understand the design and the course of its development and know his role in the overall process of creating a helicopter. With this in mind, this book presents diagrams of helicopters, design, kinematic and power diagrams of the basic components of

domestic series-produced helicopters, general data on the process of designing a helicopter and necessary information from the history of helicopter construction development.

Until the present time, there has never been a text-book on the design of helicopters for middle special technical training institutions, and this work is the first attempt to fill this void. The author will be highly appreciative of all notes and suggestions aimed at improving the book. Notes and suggestions may be written to the address: Moscow, B-66, 1st Basmann Transmitter 3, "Mashino-stroyeniye" publisher.

Introduction

A helicopter is a heavier-than-air flying apparatus having capabilities of accomplishing the vertical take-off and landing, hovering in the air and moving through it in any direction with one or more air screws. The main rotor is set into motion by a motor.

The primary difference between a helicopter and an airplane is that the main rotor of a helicopter creates the lifting force not only during the movement through the air of the helicopter but also during its stationary hovering in space, while the lift force acts on the wing of an airplane only during its progressive movement.

A helicopter can take off and land vertically for which, differing from an airplane, it does not require an airport with a long takeoff and landing strip.

The capability of a helicopter to land in any place and hover stationary in the air gives it great advantages by comparison with the airplane. Due to this, the heli-copter is used as an air crane, for lifesaving work, in geological surveying and for many other purposes in the national economy. The helicopter is also widely used in the defense system of our Fatherland.

The helicopter is the only aviation transportation means which can transport cargoes which are greater than volume of its cargo compartment (externally suspended loads).

The first mention of a flying apparatus for vertical ascent -- the helicopter (helicopter in translation from the Greek means spiral wing) -- is contained in the notes of Leonardo da Vinci in the fifteenth century.

The great Russian scientist M. V. Lomonosov in 1754 created an "Aerodrome Machine" which was a full scale model of a helicopter with a watch spring, intended for lifting a thermometer into the air. From that time right up until the beginning of the twentieth century, work on the creation of a helicopter was conducted both at home and abroad; there were many projects, models and even apparatuses constructed to full scale, but the problem was not successfully solved.

Our scientists, inventors, engineers and designers made great contributions in the matter of creating helicopters. The well known Russian inventor A. N. Ladygin moved to the forefront with the idea of a main rotor with a changing pitch in 1869 and academician N. A. Rykachev suggested the realization of horizontal flight by a helicopter by means of inclining the main rotor shaft in 1870.

Problems of helicopters were illuminated in a whole series of work by the father of Russian aviation, N. Ye. Zhukovskiy. In 1911, N. Ye. Zhukovskiy and his students B. N. Yur'ev, V. P. Vetchinkin and G. Kh. Sabin created the classical theory of the propeller which is at the basis of calculations on propellers and is used at the present time. Investigations of self-turning (autorotating) screws were first conducted at the aerodynamics laboratory in Kuchino (near Moscow).

The students of N. Ye. Zhukovskiy studied many various designs for helicopters by means of their calculations and model testing. As a result of this in 1910, student B. N. Yur'ev proposed a single-screw helicopter design with two steering screws, and in 1911, he proposed a single-screw helicopter design with one tail screw which became the most widely used design in the world (Figure 1). Helicopters both at home and abroad are constructed according to this layout at the present time.

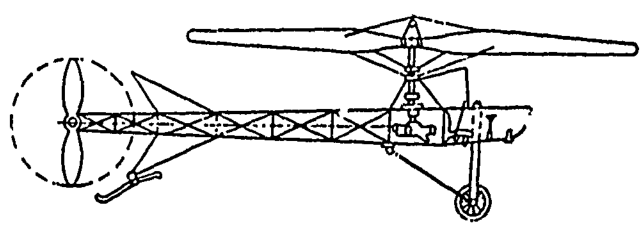

Figure 1 Helicopter of B. N. Yur'ev

In the same year, a rotor control assembly which was first used by him on his helicopter and installed on the majority of modern helicopters was invented by B. N. Yur'ev.

The helicopter of the B. N. Yur'ev's system was constructed by his students and was shown at the international exposition on automobiling and air navigation, set up in the Moscow Riding Grounds in 1912. A student of B. N. Yur'ev appeared at the Second All-Russian Air Navigation Congress which was coordinated with this exposition with a report entitled "A Helicopter of My Own Design". The jury of the exposition awarded him a small gold medal "for excellent theoretical development of a helicopter plan and its design execution".

Breakage of the rotor shaft, the absence of means and the beginning of a world war in 1914 interrupted completion of this work. He was successful in returning to it only under Soviet power.

A two-rotor longitudinal design was accomplished by the Russian designer N. I. Sorokin in a helicopter which was constructed in 1913 - 1914.

In an outstanding world accomplishment in the area of helicopter construction, the first Soviet helicopter, 1-EA, with four guide propellers, located with two each on the nose and tail of the body, was planned according to the schematic of B. N. Yur'ev at the TsAGI [Central Institute of Aerodynamics imeni N. Ye. Zhukovskiy] and was built in 1930 (Figure 2a).

This was the first real flying helicopter. Multitudinous flights to heights of 20 - 120 meters were made in it. In the process of flight testing, the helicopter rose and descended vertically, "hovered" in the air, turned around its own vertical axis and moved progressively in all directions.

In 1932, the designer, A. M. Cheremukhin, acting as pilot, attained a height of 605 meters in this helicopter.

For evaluation of this success, it should be noted that at that time, helicopters abroad did not fly, but only made jumps into the air for a short period of time. Thus, Askanio (Italy) achieved a height of only 18 meters in an experimental two-rotor coaxial helicopter.

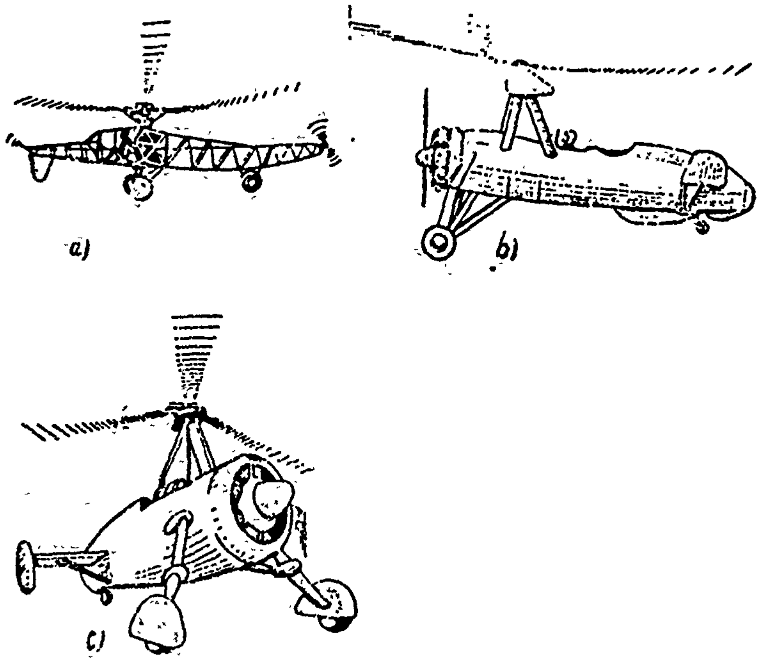

Figure 2 First Helicopters 1-EA (a) and Autogyros S-30R (b) and A-12 (c)

Helicopters of that time, were, however, complex in pilotage and unsafe in case the engine of the flying machine failed.

The basic deficiency of all helicopters constructed at that time was their insufficient stability. Each flight in a helicopter demanded a large strain on the strength and the attention of the pilot and completely exhausts him. A flight in a helicopter sometimes ended with a loss of control, a fall and breakage of the apparatus.

The insufficient stability of helicopters interferred with their practical usage. At the same time, the desire to obtain a helicopter which was reliable in pilotage and would accomplish a vertical takeoff and landing forced designers to find new means for overcoming the difficulties which arose in this area.

A large role in overcoming these difficulties was played by autogyros. Work on them began to be conducted

at the beginning of the twentieth century as the result of increasing cases of flying accidents with airplanes.

The fact of the matter is that during the years of the First World War, airplanes, equipped with gun and bomb armaments, became significantly heavier. The load per square meter of wing surface increased and airplanes became very sensitive to a loss of speed. A mistake of the pilot which allowed the airspeed to decrease lower than that admissible instantaneously led to the airplane's entry into a spin -- an uncontrollable spiral fall. This most often ended in catastrophe.

To solve this problem, the Spanish designer Juan de la Sierva proposed to replace the airplane's wing with a large propeller, leaving all the remaining parts unchanged. The propeller was not connected with an engine. The shape of the propeller was selected so that it turned due to the onrushing air stream, creating a lift force. This apparatus, called an autogyro, could even descend vertically, since the lifting force arising during self-turning (autorotation) of the screw supported the autogyro. The autogyro could not, however, hover like a helicopter.

In this way a new type of flying machine -- the autogyro -- appeared, occupying the intermediate position between the airplane and the helicopter.

Figure 3 shows the interacting forces conditioning the flight of an airplane, autogyro and helicopter.

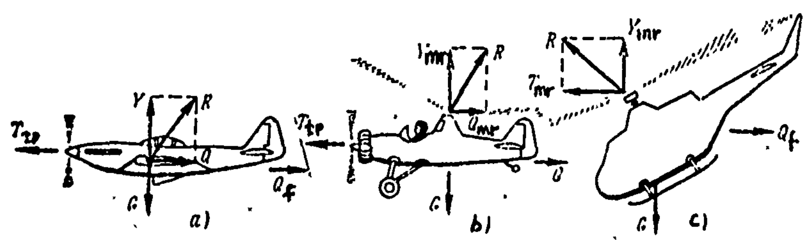

Figure 3 Interacting Forces During Flight of Propeller Flying Machines
a - airplane, b - autogyro, c - helicopter, G - weight, Y - lifting force of wing, Y_{mr} - lifting force of main rotor, Q - drag of wing, R - vector of aerodynamic forces, Q_f - drag of fuselage, T_{tp} - thrust of tractor propeller, T_{mr} - thrust of main rotor, Q_{mr} - drag of main rotor

Multitudinous investigations and experiments with autogyros led to an articulated fastening of the main rotor blades to its hub, providing their free flapping during rotation of the rotor and providing equal distribution of the lift force along the area described by the main rotor in horizontal flight.

The first autogyros had normal aircraft controls. The next important step in the development of autogyros was control of the rotor.

The first flight of a modified S-19 autogyro with a satisfactory design for main rotor control was accomplished in 1932, and in 1936, a so-called "Autodynamic Hub" was installed on a S-30R experimental autogyro. This hub increased the dynamic stability of the rotor apparatus to a larger degree than did the usual articulated hub and the autogyro with it accomplished a flight without a ground run (see Figure 2b).

Corresponding fastening of the blade hinges provided the possibility for decreasing the angle of attack of the blades and thereby decrease the lift force and any resistance of the rotor being turned by the engine. This allowed the rotor to be accelerated before takeoff to a rotation speed greater than that for autorotation and a decrease in engine revolutions (pulling the throttle) allowed a rapid increase in the lifting force, and the machine accomplished a leap into the air.

Due to the rotor control rod, the autogyro, having broken ground, immediately accelerated and accumulated sufficient horizontal speed to be supported in the air. This was called a leaping takeoff. This maneuver was rather complex and the designers therefore had to encounter a multitude of difficulties while conducting experiments.

Soviet designers built a number of original autogyros. Some of them significantly surpassed foreign models in power and dimensions.

The first Soviet autogyro KASKR-1 was built in 1929 by engineers N. I. Kamov and N. K. Skrzhinskii. After that, the TsAGI 2-EA autogyro was built at the TsAGI by engineers A. M. Cheremukhin, V. A. Kuznetsov, I. P. Bratukhin and others.

A whole series of consequently developed designs for autogyros was created by V. A. Kuznetsov: A-4, A-6, A-8

and N. K. Skrzhinskiy, A-12 (see Figure 2c). The A-7 autogyro, designed by N. I. Kamov, was series-built in 1940, and took part in combat operations of our forces during the Second World War.

The department of special designs in the TsAGI, which was directed by A. M. Izakson, during the period from 1930 until 1937 developed autogyros as well as the 3-EA, 5-EA and 11-EA helicopters.

As the result of generalizations from experience in creating autogyros, the main rotor system underwent a qualitative leap in helicopter construction. As soon as the articulated rotor and controls of autogyros were applied to helicopters, the latter began to fly stably.

The new rotor solved not only many problems of stability, control and strength but also the major problem, that of flight safety. Engine stoppage was no longer feared to a helicopter: its rotor changed over to an autorotation mode and created sufficient lifting force for a safe landing.

Thus, due to works with autogyros, both our helicopters and foreign ones reached a new stage in their development in 1937 -- the stage of also achieving essential perfection.

The 11-EA helicopter (Figure 4) was built in 1938 at the TsAGI under the guidance of I. P. Bratukhin. The helicopter layout of V. N. Yur'ev was used in it, using a six-bladed main rotor and two steering propellers whose cross sectional shapes were replaced with air foils. Taking off like a normal helicopter, in horizontal flight it transformed into an autogyro. During horizontal flight, the main rotor turned (autorotated) due to the oncoming air stream, and all power was transmitted to the two tractor propellers.

In 1937, the German firm Fokke built the FW-61 helicopter (Figure 5a) on which were two main rotors, located along the sides of the girder, which rotated in opposite directions, eliminating the torque moment.

In 1938, the well known aviation designer Sikorskiy built the VS-300 single rotor helicopter (see Figure 5b) with one steering rotor and in 1942, he built the R-5 helicopter in a small series. An improved version of the R-5 received the designation S-51 in 1945.

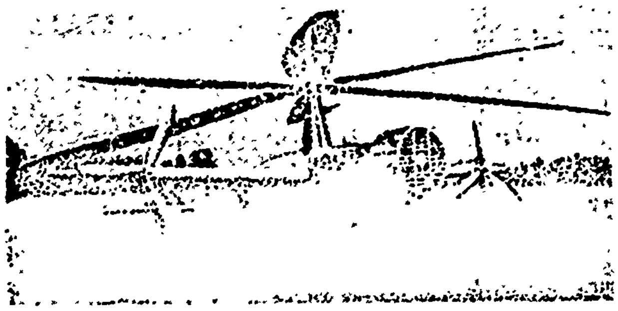

Figure 4 11-EA Single-Rotor Combination Helicopter

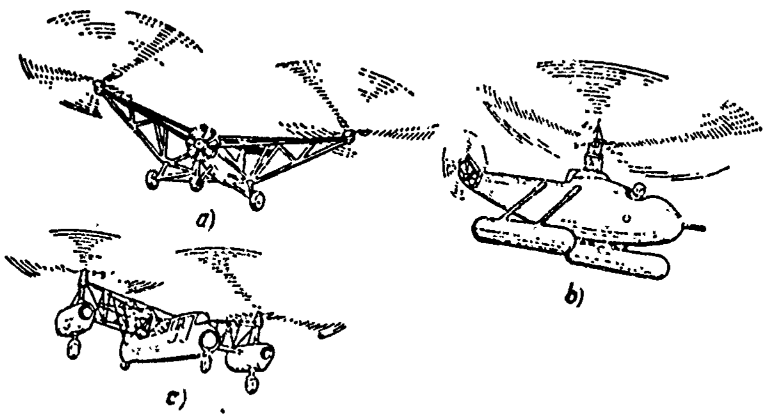

Figure 5 First Experimental Helicopters in which the Experience of Autogyro Construction was Used:

a - FW-61, b) VS-300, c) "Omega"

In 1939 - 1940 in the USSR, the "Omega" lateral arrangement helicopter was built on the design of I. P. Bratukhin (see Fig. 5c). This helicopter showed high flying data. A further development of this layout became the B-11 helicopter, also of his design. Both helicopters were demonstrated at air parades in Moscow in 1948 and 1949.

In 1949, a coaxial helicopter designed by N. I. Kamov was built and shown at the air parade and became known by the name "Air Motorcycle".

The first helicopter in the Soviet Union which received wide practical usage was a helicopter designed by M. L. Mil', the Mi-1 (Figure 6) which was put into operation in 1950. Several years earlier, the American helicopters Sikorskiy S-51, L-47 and Pyasetskiy PV-3 appeared in series, as did the English helicopter Bristol-171.

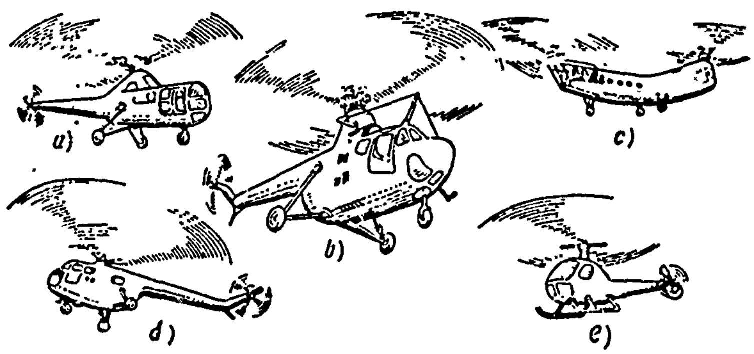

Figure 6 First Series-Produced Helicopters Receiving Practical Usage:

a - S-51, b - Mi-1, c - Pyasetskiy helicopter, d - Bristol-171, e - Bell-47

By the end of 1952, the Mi-4 transport-assault helicopter designed by M. L. Mil', doubling the Sikorskiy S-55 helicopter (Figure 7a) in maximum gross weight, engine power and pay load appeared in series production.

The Yak-24 helicopters, the largest series-produced in the world, designed by A. S. Yakovlev (Figure 8) were first shown at the air parade in Moscow in 1955. The main rotor system of the Mi-4 series-produced helicopters was used in this helicopter.

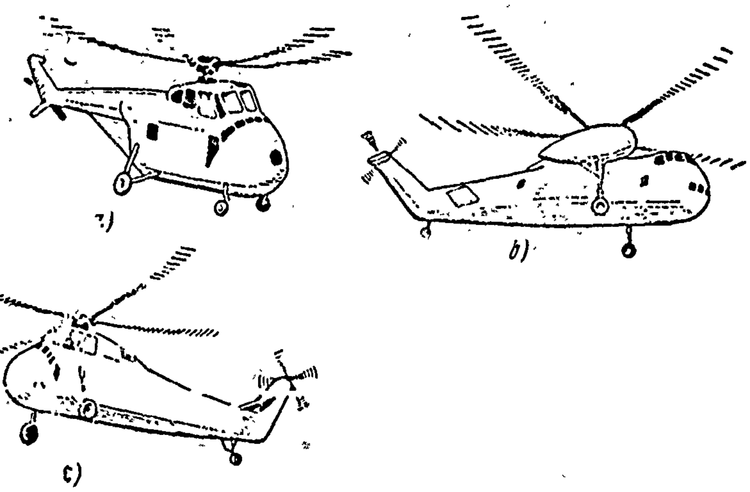

Figure 7 Foreign Helicopters:

a - S-55, b - S-56, c - S-58

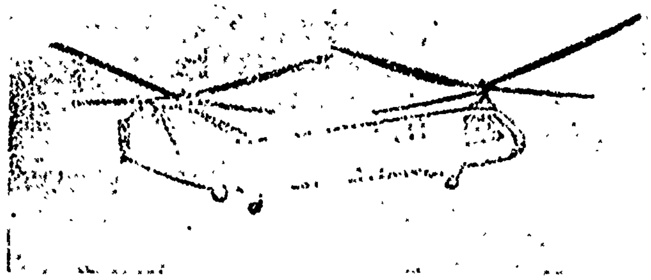

Figure 8 Yak-24 Longitudinal Arrangement Helicopter
Designed by A. S. Yakovlev

The well known designer N. I. Kamov created a whole series of helicopters of coaxial layout: from the "Flying Motorcycle" the Ka-10 helicopter to two-and three-place Ka-15 and Ka-18 helicopters (Figure 9) and the Ka-26 universal helicopter for the national economy.

The most wide usage in the national economy and in the defense system of our country has been received by the Mi-1, Mi-2, Mi-4, Mi-8, Mi-6 and Mi-10 helicopters of single rotor layout, from a light one to the heaviest helicopter in the world. (Figure 10).

Helicopter construction has developed along two directions -- that of increasing pay load and that of improving the flying, technical and economic characteristics.

Increasing helicopter pay load in the process of the development can be traced to the results of work of two design bureaus, which succeeded in practically bringing experimental models to a condition which was suitable for operation and mastering their series production (Table 1).

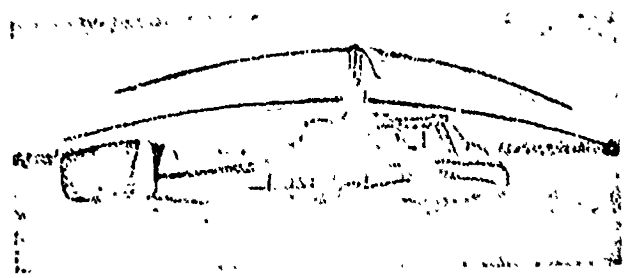

Figure 9 Ka-18 Coaxial Layout Helicopter Designed by N. I.Kamov

The use of helicopters in the national economy has moved questions of economy into the leading plan. The determining role is played by the cost of an hour of helicopter operation, on which the reserve of components has a great effect. Therefore, one of the essential problems of the designer became the problem of increasing the fatique strength of helicopter components.

Table 1

	a Вертолеты					
	b СССР			c США		
	d Ми-1	Ми-4	Ми-6	S-51	S-58	S-64
e Год выпуска	1948	1952	1957	1946	1954	1962
f Грузоподъемность в т	0,3	1,2—1,6	8—12	0,3	1,2	5—6
g Полетный вес в т	2,3	7,2	39—41	2,3	6,0	17,0

Key: a) helicopters, b) USSR, c) USA, d) Mi, e) year of production, f) pay load in t, g) maxi gross weight in t

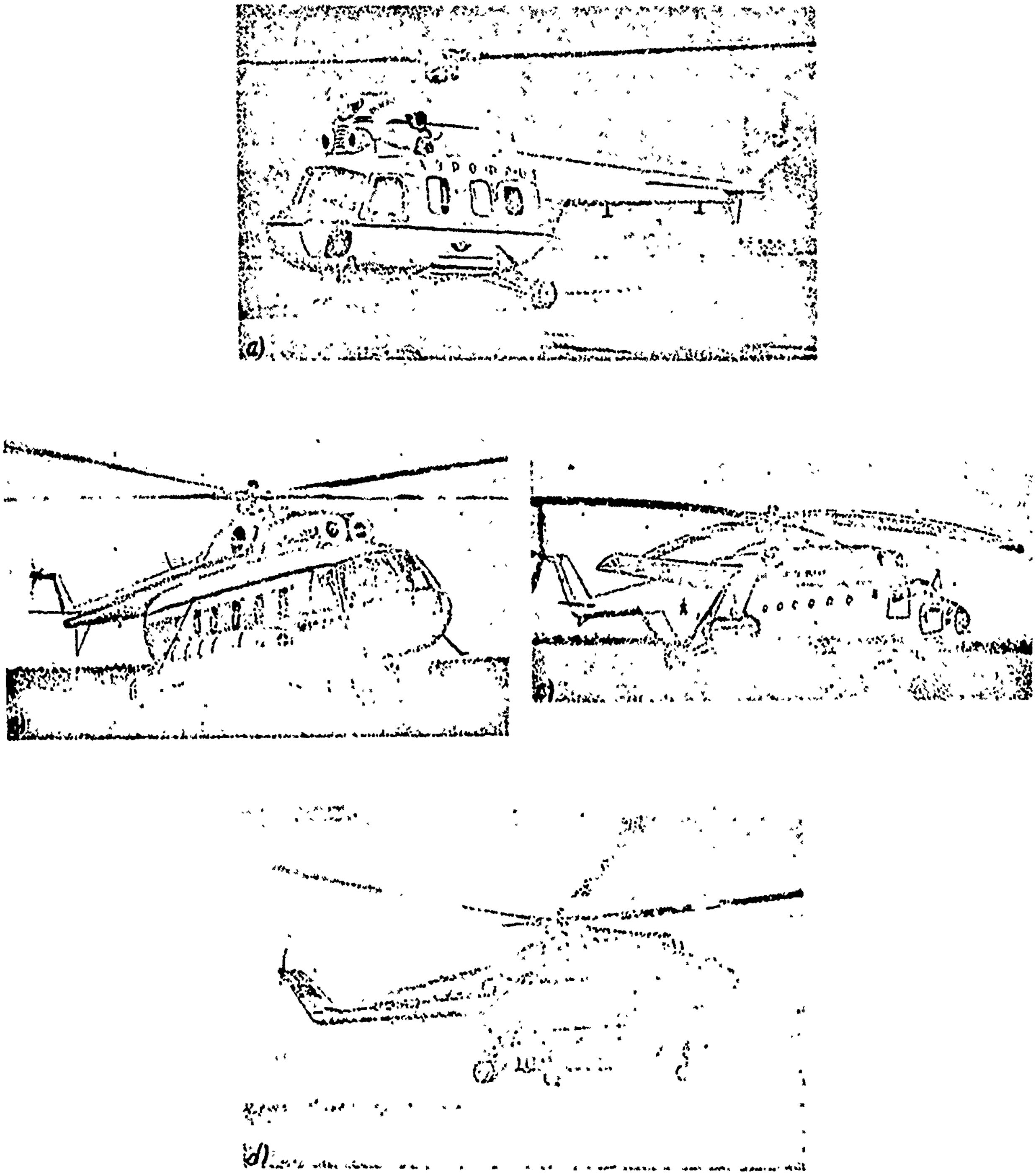

Figure 10 Single-Rotor Helicopters Designed by M. L. Mil'
(a) Mi-2, (b) Mi-8, (c) Mi-6, (d) Mi-10

The development of turboprop engines with a significantly smaller relative weight than piston engines allowed the load ratio of helicopters to be increased while maintaining the same dimensions of the main rotors.

Figure 11 shows the development of the most widely used helicopters. The line of their development according to dimensions on a base of piston engines (solid lines) is interrupted in 1953. After this, as turboprop engines of the required dimensions were created, second generation helicopters appeared over 5 - 10 years (the points corresponding to them on the drawing are connected with the original models by dotted line).

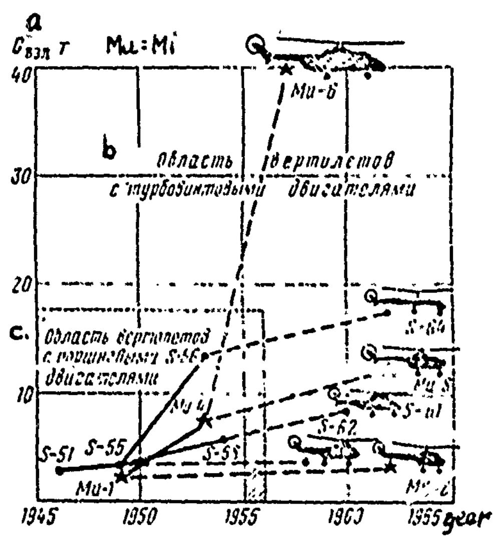

Figure 11 Development of Helicopters by Dimension

Key: a) t/o gross weight, t, b) area of helicopters with turboprop engines, c) area of helicopters with S-56 piston engines

Thus, the S-55, S-56 and S-58 American helicopters with piston engines served as prototypes for the corresponding turboprop S-62, S-64 and S 61 helicopters.

The Mi-2 and Mi-8 Soviet turboprop helicopters are also development of the widely known Mi-1 and Mi-4 helicopters.

The appearance of combination helicopters using tractor propellers in progressive flight as was the case earlier in

autogyros represents great interest. Such are the "Rotodyne" rotor wing (Figure 12) designed by Hilson and especially the Ka-22 rotor wing by the Soviet designer N. I. Kamov (Figure 13), which in 1964 established world records for machines of this type in speed (360 km/h) and pay load (16 t).

Helicopters with auxiliary jet engines are a development of combination helicopters with tractor propellers.

A further development in this direction is the Lockheed AH-56A combination helicopter (Figure 14) which is intended for escorting assault-transport helicopters and supporting ground operations with fire from the air by its on-board armaments -- cannons, machine guns, grenade launchers, rockets and antitank missiles.

The helicopter has electronic equipment and its speed at ground level is over 400 km/h.

Equipped with suspended fuel tanks, in the long-range version it can make a stopless flight over a distance of over 4600 km.

A peculiarity of the combination layout of a helicopter is the use of a main rotor with a flexible fastening of the blades in combination with a small wing for the almost full unloading of the main rotor at high horizontal flight airspeeds. The thrust propeller is located on the tail part of the fuselage. A common reduction gear with a differential serves to drive the steering and thrust propellers. At high airspeeds. almost all the power of the engine is transmitted to the thrust propeller. Only the thrust propeller works through the controls. The tail empennage of the helicopter consists of a stabilizer and a vertical stabilizer beneath the fuselage, on the end of which is fastened the tail wheel of the chassis.

The main gear of the chassis retract into fairings along the sides of the fuselage. The front parts of the fairings are the fuel tanks.

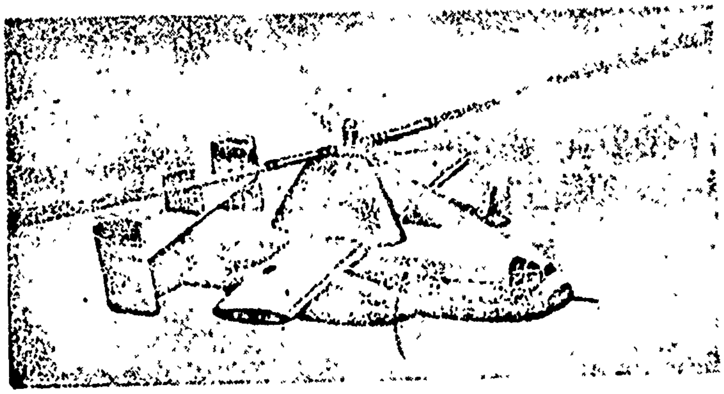

Figure 12 "Rotodyne" Rotor Wing

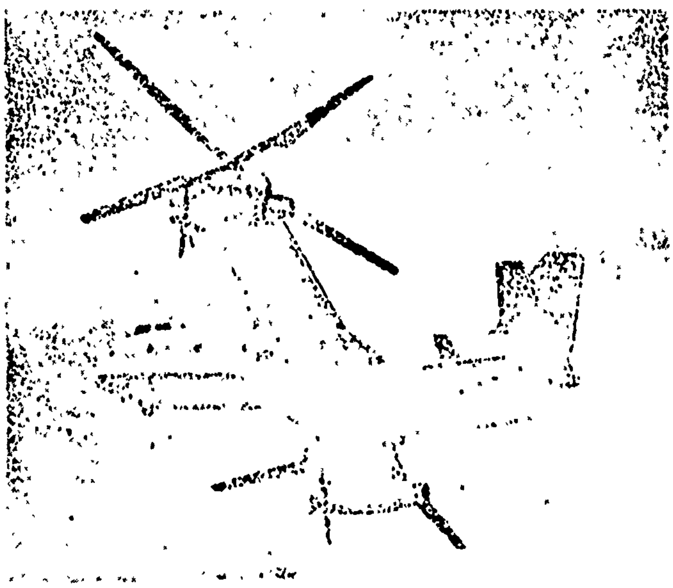

Figure 13 Ka-22 Rotor Wing

Figure 14 Lockheed AH-56A Helicopter

Chapter 1

Helicopter Layouts

In the majority of modern helicopters, the main rotor is brought into rotation through a transmission from turboprop engines. The methods of equalizing the reactive torque moment of the main rotor of the helicopter with a mechanical drive basically determines the layout of the helicopters. During rotation, the main rotor experiences the effect of the reaction moment M_{react}, which is the reaction of the air and its equal M_t, where M_t is the torque moment on the main rotor shaft. This moment attempts to turn the fuselage of the helicopter in a direction opposite that of the main rotor's rotation.

Single rotor helicopters having the main rotor mechaniically driven have a steering rotor which is situated on a long tail boom behind the plane of rotation of the main rotor (see Figure 10). The thrust created by the steering rotor allows the reaction torque moment to be equalized. By changing the amount of the steering rotor thrust, it is possible to accomplish yaw control, which is the rotation of the helicopter relative to its vertical axis.

The single rotor layout of a helicopter is the most widely used one at the present time. The advantage of this layout is the relative simplicity in its design -- one main rotor, simple controls and one main transmission. The engine power expended for driving the tail rotor (8 - 10%) and also the presence of a long tail which increases the dimensions of the helicopter is one of the essential deficiencies of the layout.

In the two-rotor helicopter layout, the reaction torque moment is brought into equilibrium in all cases by combining rotors which turn in opposite directions. Two-rotor helicopters can have various locations of the main rotors.

The coaxial layout of helicopters can be treated as a specific case in two-rotor layouts, in which the shafts of both main rotors coincide (see Figure 9). Tn this layout the shaft of the upper main rotor passes through the entire

shaft of the lower one. The main rotors turn in opposite directions with the same number of revolutions and their reaction moments are mutually cancelling. The planes of rotation of the main rotors are separated from each other by some distance so that the blades of the upper and lower rotors cannot collide in any flight configuration.

Directional control of a helicopter with a coaxial layout is provided by the differential (decreasing in one and increasing in the other) change in the angle of upper and lower main rotor blade setting. The difference arising between the torque moments on the main rotors causes the helicopter to turn in the required direction. Consequently, differential control of pitch replaces the directional control in this helicopter. Longitudinal and lateral control is effected by simultaneously inclining both main rotors.

The basic advantage of helicopters of the coaxial layout is their relatively small dimensions, however, the complexity of their transmissions and other difficulties have limited the widespread development of this layout.

In helicopters with crossing rotors, the main rotors are situated at an angle to each other. Rotation of the rotors is synchronized so that in any position the blades of one rotor will pass above the blades of the other one. The small dimensions of the helicopters is the advantage of this layout.

Due to the cross sectional slant of the main rotors, it is necessary to locate their hubs at a greater height than, for instance, in single rotor helicopters so as to assure the safety of the helicopter's operation when it is on the ground with the rotors turning. This measure leads to an increase in the weight of this helicopter design.

In the tandem helicopter layout, the main rotors are installed on the ends of the fuselage (see Figure 8). Turning in opposite directions, the main rotors are synchronized so that the blades of one rotor always pass between the blades of the other one during rotation. The reaction moments of the main blades, acting on the fuselage, are mutually cancelling. All loads from the main rotors are absorbed by the force beam (fuselage) which fulfills the role of a cargo or passenger cabin. The force beam is executed so that it is rigid and relatively light.

From the point of view of aerodynamics, helicopters of this layout have an essential deficiency -- the negative effect of the front main rotor on the rear one at low air-speeds.

In the side-by-side two-rotor helicopter layout, the main rotors are located on a single plane along the sides of the fuselage and turn in opposite directions with an identical number of revolutions (see Figure 13).

From the point of view of aerodynamics, the side-by-side layout of main rotor location is the most expedient one, but the cantilevers (wings), taking up the loads from the main rotors, make the designs for helicopters of this layout heavier.

The multirotor layout includes helicopters having more than two main rotors. Helicopters of this design have not received widespread development, since increasing the number of main rotors installed on them leads to their more complex and clumsy design.

Helicopters with Wings. To increase the airspeed of a helicopter, besides the main rotor, a second load-bearing element -- a wing -- is installed on it. During flight with a horizontal velocity, a lifting force is created on the wing, the result of which is that the main rotor is unloaded by the amount of the wing's lifting force. Due to this, the required angle of blade attack is decreased and retreating blade stall is moved to a higher air speed. Figure 10c shows a helicopter with wing. The wing is located in height is such a manner that during hovering operations it has a minimum effect on the work of the main rotor.

Rotor Wings. Due to a decrease in the required lifting force on the main rotor of a helicopter with a wing and an increase in drag from the wing, the main rotor must be inclined forward at a large angle, and since the amount of the inclination of the main rotor forward is limited according to aerodynamic and design conformities, in order to obtain even higher helicopter air speeds, additional engines are installed with either thrusting or tractor propellers. A helicopter with a main rotor, wing and tractor (thrust) propellers is called a combination or rotor wing, and therefore it is a combination of a helicopter and an airplane (see Figures 4, 13 and 14).

A rotor wing takes off like a helicopter. During takeoff, the engine power is almost all transmitted to the main rotor, which creates the vertical thrust, and the thrusting propellers are used only for equalizing the reaction torque moment of the main rotor. For transferring to horizontal flight, the main rotor is inclined forward with the cyclic pitch control and horizontal thrust is created; horizontal thrust is also obtained with the thrust (tractor) propellers.

With increased airspeed, the wing, creating a lift force, unloads the main rotor, which will lead to a decrease in the latter's torque moment.

When horizontal flight is established, all the power of the engines is transmitted to the tractor propellers and the main rotor is disengaged from the transmission and rotates freely due to the effect of the onrushing stream of air, creating lift.

Control of a rotor wing differs somewhat from control of a normal helicopter. In the helicopter flight configuration, the rotor wing is controlled similarly to a normal helicopter with the cyclic pitch control of the main rotor (longitudinal and lateral control) and the tractor propellers 'directional control); and in the autogyro flight configuration, the rotor wing is controlled similarly to an airplane with aerodynamic control surfaces.

Rotor wings with a mechanically driven main rotor can be created with both a single rotor layout with steering propellers and with two rotor side-by-side, tandem and coaxial layouts.

Along with such advantages as in an increase in maximum airspeed and operating range by comparison with normal helicopters, the rotor wing with mechanical drive also has some very essential deficiencies, particularly, the presence of the complicated transmission. Replacing the main rotor drive mechanical transmission with a jet one simplifies and eases design of the rotor wing.

With a jet powered main rotor, the moment of the latter due to aerodynamic forces is equalized by the moment created by the thrust of the jet engine or nozzles which are located on the ends of the blades. In this case, the total torque moment at the main rotor hub is equal to zero.

Two types of main rotor jet power are possible:

1) Jet compressor power (Figure 15), with which compressed air from the compressor, powered by an engine, is forced through the hub and blades of the main rotor to jet nozzles located on the ends of the blades;

2) Power with jet engines (TRD, PVRD and PuVRD) installed on the ends of the blades.

In helicopters with a jet powered main rotor, there is no mechanical transmission. This decreases the cost of design to a significant degree and increases the load ratio of the helicopter. However, due to the low coefficient of effeciency of the compressor drive, the complexity of creating an engine to work in the field of high centrifugal forces on the ends of the blades and the great additional noise created by the jet power, helicopters with this power for the main rotor have not yet received widespread practical application.

Figure 12 shows the English "Rotodyne" rotor wing with a compressor driven main rotor. This helicopter has a highly placed wing with turboprop engines installed on it. The power from these engines can be transmitted to the tractor propellers and to auxiliary compressors. During vertical takeoff, the tractor screws are "feathered" so that they do not create any horizontal thrust and require minimum power. In this case, almost all the power is required by the auxiliary compressors. Air in the compressors is compressed and sent along passages in the distributing installation of the main rotor hub. There are burners on the ends of the main rotor blades where, together with air, fuel is pumped. The force of the reaction of gases flowing from the burners brings the main rotor into rotation. After this, as the helicopter accomplishes its vertical takeoff, its main rotor is inclined forward with the cyclic pitch control, as the result of which the horizontal component force arises and the helicopter moves forward.

A basic deficiency in a rotor wing is the complexity of its design. The rotor wing actually has two load-bearing systems which create lift (the wing and the main rotor) and two engines which create horizontal thrust (the main rotor in the helicopter configuration and tractor propellers in the autogyro configuration). During hovering and vertical takeoff, when the main rotor creates the lifting force, the wing and the tractor propellers are not used. Both load-bearing systems and both types of engines are worked together only during the transfer configurations. As air

speed is increasing, the rotor wing can transfer to a configuration in which all the lift will be created by the wing and the turning main rotor will only interfere with flight, creating additional drag. In order to increase airspeed, it is necessary to streamline the main rotor in some way or another, which is to say transform the helicopter into an airplane.

Flying apparatus which accomplish a takeoff and landing similar to a helicopter and horizontal flight similar to an airplane are called helicopter-airplanes. In other countries, such flying machines are convertoplanes, which is to say converted airplanes. Helicopter-airplanes are a further step along the course of increasing the airspeed of propeller apparatuses which take off vertically.

So that the main rotor does not interfere with flight at high airspeed, it is proposed in some plans that it either be stopped in flight or retracted into special compartments located along the fuselage.

A diagram of the main rotor retraction sequence of a helicopter-airplane is shown in Figure 16. During takeoff and landing, gases from the turbojet engine pass to jet nozzles on the ends of the blades. Coming from the nozzles, the gases create thrust and put the main rotor into rotation. Horizontal flight is accomplished with the engines, gas feed into the main rotor is stopped, the rotor is stopped and lowered into the fuselage.

Considerable interest is generated by helicopter-airplanes in which the same propellers are used for take off and landings and for horizontal flight. Such a helicopter-airplane takes off and lands similar to a normal helicopter, and its propellers work as the main rotors of a helicopter, creating vertical lift.

Stability and controlability of the helicopter-airplane in the vertical takeoff and landing configurations are provided for by means of changing the thrust of the main propellers and with a small auxiliary propeller on the tail of the fuselage.

According to the altitude selected, the wing, together with the engines, rotates. The thrust of the propellers begins to have a horizontal component, accelerating the machine. At the moment when the lifting force of the wing becomes to the weight of the helicopter, the wing goes into the horizontal position.

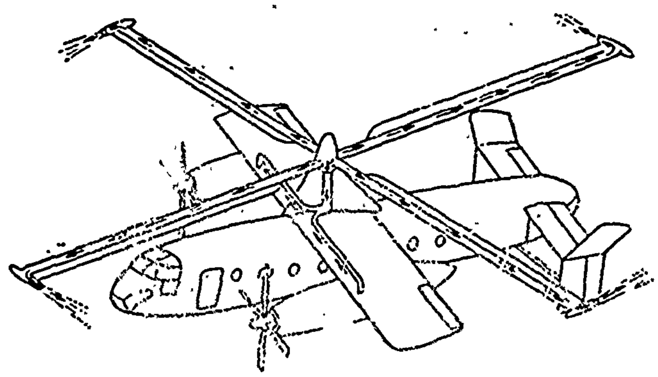

Figure 15 Diagram of Ma.u Rotor Jet Compressor Drive

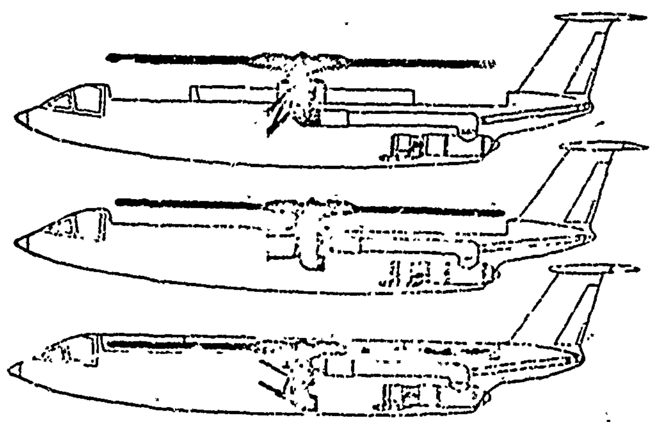

Figure 16 Diagram of Main Rotor Retraction Sequence of Helicopter-Airplane

In connection with the fact that the propellers of the helicopter-airplane must work during flight in two entirely different modes -- as a helicopter and as an airplane -- the selection of propellers to work equally well in both modes is made extremely more difficult. The process of transferring from one mode to the other represents special complexity, since during this, the position of the propellers

and the amount of forces and moments acting on them is changing.

Control of a helicopter-airplane is complex.

In the airplane configuration, the helicopter-airplane is controlled with aerodynamic control surfaces, and in the helicopter configuration, it is controlled by controlling the cyclic and collective pitches of the main rotors. Both types of control must be synchronized so that the helicopter-airplane can be controlled with the same control levers located in the cockpit. Vertical thrust in a vertically taking off airplane can be attained not only by turning the wing with the propellers but also by turning the engines on the wing, and the process of taking off, landing and horizontal flight is accomplished the same as if the wing were turned.

[Translator's Note: Pages 26 and 27, including headings for chapter 2,#1, and Figure 17 are missing from the original document.]

wing warp increases as the wing section approaches the position of equilibrium. In position 3, the wing does not stop, but continues further due to inertia. Forces P_u and P_{in} reverse their direction and therefore, the angle of warp decreases (position 4). In position 5, wing sag is maximized and angle of warp = 0. Wing positions 6, 7, 8 and 9 can be constructed similarly.

Vertical oscillations on a wing and its warping cause changes in the aerodynamic forces acting on the wing.

During vertical oscillations, the wing section lowers and raises at a definite velocity, due to which the angle of attach of the section will change. When the wing is lowering, this angle will increase and when it is raising the angle will decrease.

A change in the angle of attack of a section during vertical oscillations of the wing will cause changes in the lifting force on the wing by amount P_i. The angle of attack of the section will also change due to warping of the wing. When the wing lowers, this angle will decrease and when it raises, the angle will increase.

A change in the angle of attack of the section due to wing warping will cause a change in the lifting force on the wing by amount P_θ

P_i always acts in a direction opposite the direction of the vertical movement of the wing, and therefore this force is an oscillation damper.

Force P_θ agrees in sign with the direction of the wing's movement during oscillations and it is therefore an augmenting one.

On air speed, the work of forces P_i and P_θ will change according to the same law as governs the forces themselves.

The character of oscillation (with a damping, with a constant, and also with an increasing amplitude after the effect of an incidental disturbance) depends on the relationship between the work of the dampening and the augmenting forces during one period of oscillation. Figure 18 shows the character of the change of work A: augmenting A_{aug} and dampening A_{damp} forces are dependent on air speed V.

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Section Ob corresponds to the work of th' forces of internal friction, which depend on air speed.

The point of intersection of straight line A_{damp} and parabola A_{aug} determines the critical velocity of flutter. At this velocity, oscillations occur with a constant amplitude. At airspeeds V less than V_{cr}, the oscillations are damped, and at V greater than V_{cr}, oscillations are increased in amplitude. For safety in flight, it is necessary that V_{cr} is higher than the maximum possible airspeed.

The critical velocity of wing flutter can be increased by increasing the rigidity under tortion GJ_{cr} and bringing the center of gravity closer to the center of rigidity by setting an antiflutter load on the leading edge of the wing. The critical velocity of wing flutter does not depend on rigidity under bending.

Main rotor flutter arises for the following reasons. The torque moment relative to the axis of the hinge will lead to the appearance of twisting oscillations of the blade due to forces of inertia acting during the flapping movement of the blade. In this, twisting oscillations with a phase shear of 90 degrees in relationship to the flapping oscillation will increase especially strongly at frequencies close to the frequency of the inherent oscillations of the blade under tortion. This component of twisting oscillations will lead to augmentation of the flapping oscillations of the blade. When this augmentation is stronger than the force dampening the oscillations, flutter (flapping) occurs. The number of main rotor revolutions at which flutter occurs is called the critical revolutions of flutter.

Moving the center of gravity of the blade toward the front edge, the same as decreasing the flapping compensator, improves fluttering characteristics (increases the critical revolutions of flutter).

The critical number of revolutions for flutter basically depends on the relative location of the center of gravity of blade elements and the section aerodynamic center, and therefore moving the section aerodynamic center from the front edge along the the core is just as effective as moving the blade center of gravity toward the leading edge.

The most effective methods of improving the flutter characteristics of a blade are:

1) Moving the center of gravity of the blade toward its leading edge as much as possible under the design conditions;

2) Moving airfoil profiles, which have the rearmost possible position of centers in working configurations of flight;

3) Changing the position of the axial hinge if it can be done within wider limits than moving centering;

4) Creating a sufficiently high blade rigidity under tortion;

5) Creating a sufficiently high rigidity in the control system.

Flexure-Aileron Flutter

To simplify inspection of the physical picture of flexure-aileron flutter, we will consider the wing to be absolutely rigid during tortion, and the aileron to be freely suspended on its axis of rotation, which is to say not connected with its control rods.

The wing with the aileron is in a condition of equilibrium in position 1. After the disturbing impulse, the wing, under the effect of elastic forces, recovers ito its neutral position with acceleration (Figure 19). The aileron, due to the effects of the moments of inertial forces P_{in} which are applied to the center of gravity of the aileron, deflects in the direction opposite the movement of the wing by angle β

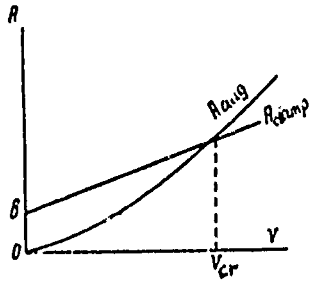

Figure 18 Changing Augmenting and Dampening Forces During Period of Oscillation Depending on Airspeed

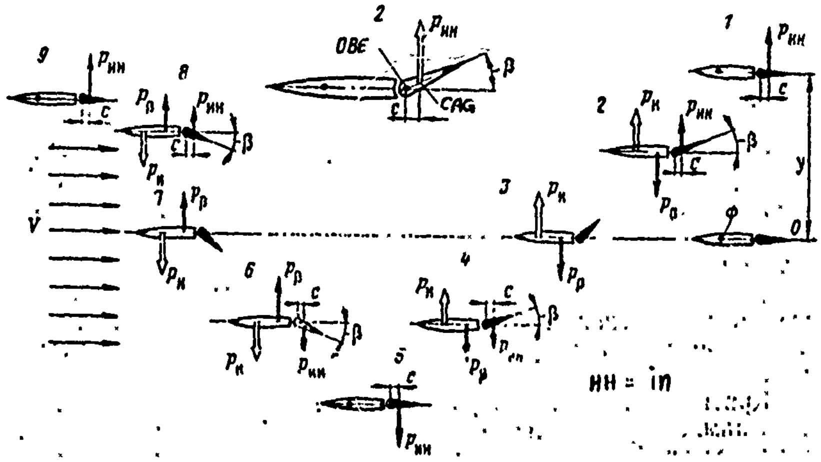

Figure 19 Flexure-Aileron Flutter of a Wing:

V - air speed, R_β - aerodynamic force arising due to aileron deflection, β - angle of aileron deflection, OBE - axis of aileron rotation, ACG - aileron center of gravity, c - distance from aileron angle of rotation to its center of gravity. The remaining designations are the same as in Fig.17.

An additional aerodynamic augmenting force P_i arises as a result of the aileron's deviation, and an additional dampening force P_β appears as the result of the vertical speed of the wing.

The work of the augmenting forces and dampening forces depending on velocity for the case under review can be represented in the form of graphs similar to the work of forces during flexure-tortion flutter.

In order to overcome the arising flexion-aileron flutter, it is necessary to eliminate the moment from the forces of inertia. For this, it is necessary to design the aileron so that its center of gravity coincides with its axis of rotation and there is no slack in the ailerson control system.

If the necessary position of the center of gravity is difficult to realize with the design measures, a load is applied to the leading edge of the aileron to provide the necessary balancing of it.

Oscillation of the empennage can be similar to oscillation in the wing, due to the similarity in their design. Besides this, empennage oscillations can occur in combination with bending and tortion of the fuselage. Therefore, the number of possible types of flutter can be large. The most commonly encountered forms of empennage flutter are: flexion-control, tortion-control and flexion-tortion-control

Flexion-control flutter of the empennage is accompanied by bending of the fuselage and deflection of the elevators. From a physics side, this flutter is similar to flexion-aileron flutter.

Tortion-control flutter of the horizontal stabilizer is accompanied by deflection of both halves of the elevator in opposite directions and tortion of the fuselage. This deflection can occur due to flexibility in the control linkage and warping of the control surface itself.

In flexion-tortion-control flutter of the vertical stabilizer, oscillation is the summary movement of the two preceeding types of flutter, which is to say that it is accompanied by bending and tortion of the fuselage and deviation of the control surface also as the result of control linkage flexibility and due to warping of the control surface itself. The basic measures for combating empennage flutter are the same as for combating wing flutter -- weight balancing, increasing empennage rigidity under tortion and eliminating flexibility and free play in the control system.

Wing Instability

Wing instability is the phenomenon of deformation instability of the wing in the air stream at some determined velocity without the appearance of oscillation. The main determination of instability is the position of the axis of rigidity and the center of pressure.

The physics of instability can be explained in the following manner.

Let us imagine a wing whose axis of rigidity is located aft of the center of pressure. With an increase in the angle of attack, the aerodynamic moment arises in the wing which attempts to twist the wing. This will lead to an increase in the angle of attack and to a further increase in the lift force. The increasing lift force, in turn, is the

reason for a further increase in the angle of tortion. For velocities lower than the critical one, which is called the velocity of instability, the increase in the angle of tortion and the lift force becomes less and less until a condition of stable equilibrium is reached. When the air-speed exceeds the velocity of instability, the increase in the aerodynamic tortion moment exceeds the gain of the flexible recovery moment and the wing is destroyed.

Decreasing Effectiveness and Reversing of Control Organs

Decreasing effectiveness and reversing (reverse action) of control organs, like instability, is a result of flexible deformation of the load-bearing surface during deflection of the control organs.

The relationship between the lift force obtained during deflection of the control organs of actual flexible load-bearing surfaces and the lift force created by an ideal rigid design is called the effectiveness of the control organs.

Effectiveness in ailerons can be expressed not only through a force relationship but also through a relationship of moments. In this case, the change in the arms of these forces due to flexible deformation is calculated.

The physical side of this phenomenon, in connection with the decrease in aileron effectiveness, can be explained in the following manner. To create a bank in the flying apparatus, it is necessary to deflect the wing aileron by some angle. Deflection of the aileron will lead not only to an increase in the lift force, but will also create an aerodynamic moment which twists the wing, consequently changing its angle of attack. This will in turn lead to a change in the lift force. In sum, the role moment will be created only by the difference in the moments of these forces.

With an increase in velocity, the decrease in the lift force due to the decrease in the wing's angle of attack will be stronger than the increase in the lift force caused by the aileron deviation. There exists an airspeed at which aileron effectiveness turns out to be zero.

This velocity bears the name critical airspeed of aileron reversing. At an air speed greater than the critical velocity of aileron reversing, effectiveness becomes negative and, consequently, the effect of the ailerons will be reversed.

Aileron effectiveness and the critical velocity of reversing depend on the aerodynamic, geometric and rigidity characteristics of the wing and aileron. By changing the parameters of the aileron or rigidity characteristics of the wing, it is possible to increase the critical velocity of reversing if the latter lies within the flight range (lower than the maximum air speed).

Buffeting

Buffeting is unsteady oscillations of the design elements of a flying apparatus which are brought about by aerodynamic impulses causing an accompanying stream behind the wings, blades, projections of the fuselage and other elements. Figure 20 shows a diagram of deformation of the changing aerodynamic loads (impulses) with the flow-path of the wing at high angles of attack. In this case, the distribution of pressure along the core is characterized by large drops. The greatest suction will be in the area in immediate proximity to the leading edge of the wing. As the result of large drops in pressure, air particles located close to the enveloped body begin to flow along the profile in the area of maximum suction. This is a reverse movement of air particles and will lead to the separation of the boundary layer from the surface of the body. The smoothness of flow-past portion of the profile is disrupted, forming a zone of air stream breakage consisting of intensive vortices.

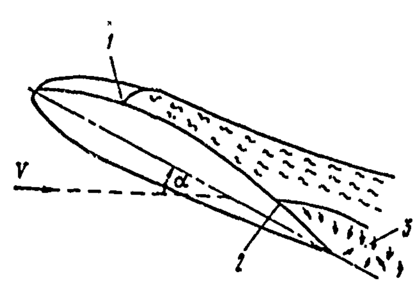

Figure 20 Flow-Past of a Wing at High Angles of Attack:

1 - point of laminer layer separation, 2 - point of turbulent layer separation, 3 - separated vortices, V - air speed, α - angle of attack

The structure of the separated stream is extremely complex. Pulsing loads act on the streamlined body itself. Besides this, they act on all the parts or elements of design where the adjoining vortices of the stream fall. If a pulsing load is applied to a flexible body, it will accomplish oscillations with prevailing frequency equal to the frequency of natural oscillations. In this case, resonance will occur with a frequency which coincides with the frequency of natural oscillations of the flexible system.

The amplitude of oscillations set up during residence depends on the energy of the separated vortices. The energy of the vortices in turn depends on the area encompassed by the separation and on airspeed.

To overcome buffeting, it is simpler and more profitable to eliminate it at its cause, somewhat increasing the rigidity of the design. It is not expedient to create projections on the streamlined surface, sharply change its configuration and so forth.

Section 2

Main Rotors

Purpose and Working Principles of a Main Roter and Requirements Outlined for It

During flight, the main rotor of a helicopter performs several functions (Figure 21a). It creates lift Y_{mr} in all flight configurations and the thrust T_{mr} which is necessary for accomplishing the progressive movement of the helicopter; longitudinal and lateral control of the helicopter is accomplished with the main rotor. In the hovering mode and during a vertical climb, the main rotor works similar to the propeller of an airplane. In progressive flight, the axis of rotation of the main rotor is inclined forward and the main rotor works in the configuration of a slanted blower. In horizontal flight, the blades of the main rotor are located not only by the effect of tip velocity ($u = \omega R$) but also by the horizontal velocity V of the helicopter. In this manner, various velocities of the air stream meeting the main rotor blade occurs at various points on the area described by the rotor.

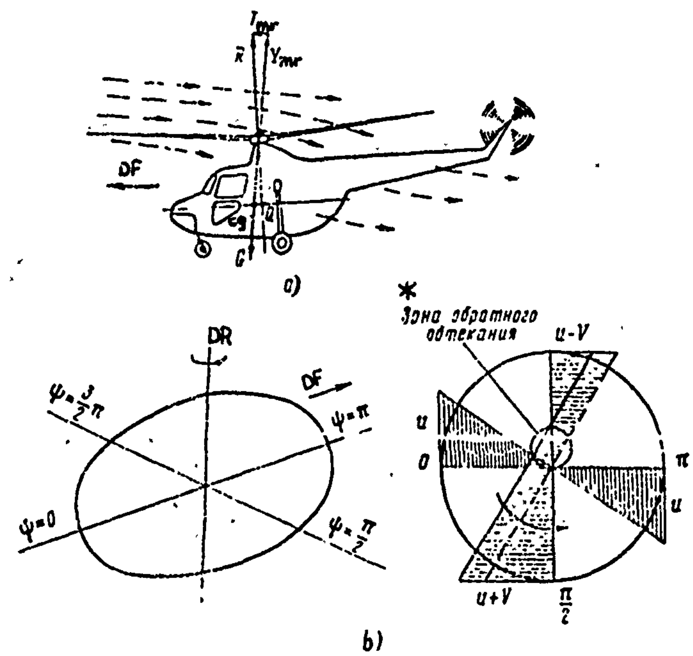

Figure 21 Work of a Helicopter Main Rotor in Horizontal Flight

a - diagram of the forces applied to a single rotor helicopter in vertical plane, b - diagram of blade flow-past of the main rotor, T_{mr} - main rotor thrust, Y_{mr} - main rotor lift, G - weight, Q - frontal drag, R - result of aerodynamic forces, DF - direction of flight, c.g. - center of gravity, V - velocity of horizontal flight, $u = \omega R$ - circular velocity of blade end, DR - direction of main rotor rotation, ψ - azimuth, * zone of reverse flow around

For convenience in inspecting the work of main rotor blades during horizontal movement of the helicopter, the understanding of angles of azimuth, characterizing the position of the blade relative to the longitudinal axis of the fuselage is introduced (Figure 21b). In the rear part of the area described by the rotor, the azimuth $\psi = 0$ is taken, and in the front, the azimuth $\psi = \pi$ is taken. In the lateral section of this area at a point where the tip velocity of the blade is added to the velocity of the horizontal movement of the helicopter, the azimuth will be $\psi = \pi/2$. The diametrically opposite point, at which velocity is subtracted, $\psi = 3/2\,\pi$

Figure 21 b shows a diagram of velocity changes along the radius of the blade for the longitudinal ($\psi = 0$, $\psi = \pi$)

and lateral ($\Psi = \pi/2$, $\Psi = 3/2\,\pi$) sections of the main rotor disc.

In that the aerodynamic forces depend on velocity, differences in lift on the blades will take place along the disc of the main rotor according to their azimuthal position. The blade, moving from azimuth $\Psi = 0$ to azimuth $\Psi = \pi/2$, will be located in a field of increasing velocity. Consequently, the thrust of the blade will constantly increase. After that, at Ψ greater than $\pi/2$, the thrust of the blade will decrease and at $\Psi = \pi$, it will be equal to the thrust at $\Psi = 0$. In that the total velocity $w = u + V$ has a lesser value at $\Psi = 3/2\,\pi$, there will be a decreased thrust in that place.

A difference in the values of thrust at azimuth $\Psi = \pi/2$ and $\Psi = 3/2\,\pi$ creates a rolling moment relative to the longitudinal axis of the main rotor. A hinged fastening of the main rotor blades to their hub was used to eliminate this deficiency. This created the possibility for a flapping motion of the blade relative to the horizontal hinge. The blade was made capable of occupying a position relative to the plane of flapping at which the total moments due to aerodynamic and mass forces relative to the horizontal hinge equaled zero. (Figure 22).

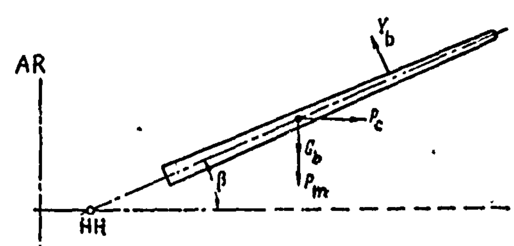

Figure 22 Forces Acting on a Blade in the Plane of Flapping:

Y_b - blade lift, P_c - centrifugal force, G_b - blade weight, P_{in} - force of inertia, β - angle of conicity, HH - horizontal hinge, AR - angle of blade rotation

Angle β between the blade and the surface of rotation is called the angle of conicity or the angle of flap. When the blade moves from azimuth $\Psi = 0$ to $\Psi = \pi/2$, blade thrust increases and the blade, withh the presence of a horizontal

hinge, begins to move upward.

Since the blade moves upward, the air rushes downward relative to it. The downward rushing stream of air decreases the true angle of attack of the blade, creating an angle of air stream slant due to the flapping motion.

Due to the fact that the angle of attack decreases, thrust also decreases. When the blade moves into the zone Ψ greater than $\pi/2$, the velocity of the air stream rushing toward it begins to decrease. The blade continues to move upward because of inertia and reaches its maximum height at $\Psi = \pi$.

Further movement of the blade takes place in the reverse order. Due to a decrease in the velocity of the onrushing air stream, thrust decreases and the blade begins to move downward.

During movement of the blade downward, the air stream will rush toward it from below. The angle of attack of the blade increases and thrust increases.

In this manner, the flapping motion of the blade evens out the thrust along the main rotor disc.

During its flapping motion, the blade, rotating relative to the axis of the main rotor, describes somewhat of a cone.

In the neutral control position, the cone described by the blades turns to the rear and is rolled to the side in the direction of the blade which is moving forward (relative to the line of flight).

The aerodynamic forces acting on the main rotor with the rotor control mechanism in the neutral position are shown in Figure 23a.

With the main rotor blower slanted, the distribution of lift along the radius of the blade periodically changes and the load moves in the direction toward the end of the retreating (moving opposite the direction of flight) blade. A typical distribution of load along the main rotor is shown in Figure 23b.

During the flight of a helicopter, the rotating blade meets an onrushing stream of air with a varying velocity. Consequently, changing aerodynamic forces will act on it.

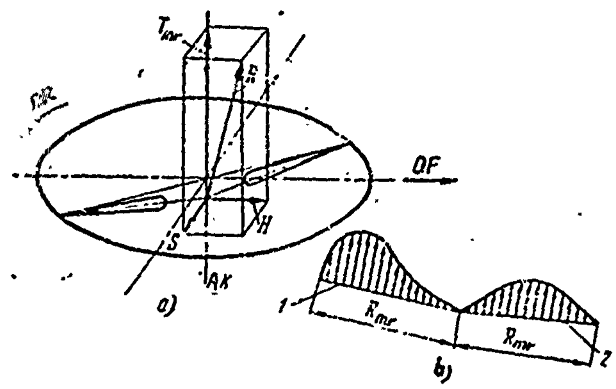

Figure 23 Aerodynamic Forces Loading the Main Rotor in Horizontal Flight of a Helicopter:

a - aerodynamic forces acting on the main rotor with the rotor control mechanism in a neutral position, b - distribution of aerodynamic loads along the radius of the blade in the horizontal flight configuration, R - equally acting aerodynamic forces of the main rotor, T_{nr} - main rotor thrust, H - longitudinal force, S - lateral force, DF - direction of flight, DR - direction of rotation, AK - axis of cone, 1 - advancing blade, 2 - retreating blade, R_{nr} - main rotor radius

The introduction of a flapping motion of the blade is one of the most significant steps in the development of helicopters. However, the flapping motion of the blade brought out an entire set of problems. Oscillation of blades relative to the vertical hinge is connected with the flapping motion as a result of the period of drag forces and Coriolis forces.

A turning and simultaneously flapping blade is loaded with Coriolis forces. At the moment the blade flaps upward, its center of gravity is shifted closer to the axis of rotation by some amount. In accordance with the law of maintaining energy, the moment of the quantity of blade movement does not change, which is to say

$$J_\omega = \text{const},$$

where J -- moment of inertia of the blade;
ω -- angular velocity of main rotor rotation.

When the blade flaps upward, the radius of the center of gravity decreases, decreasing the moment of blade inertia, and with this, the value for angular velocity must increase. When the blade flaps downward, the radius of the center of gravity increases, increasing the moment of inertia and the value of angular velocity decreases.

As the result of the flapping motion of the blade relative to the horizontal hinge, its angular velocity changes periodically. When the blade flaps downward, Coriolis forces are directed toward the side opposite that of rotation and when it flaps upward, they are in the direction of rotation. In this manner, the introduction of a horizontal hinge requires the introduction of another hinge to provide the possibility for moving the blade in the plane of rotation. This hinge received the name vertical hinge. Diagram of the hinge fastening of the main rotor blades to the hub is shown in Figure 24.

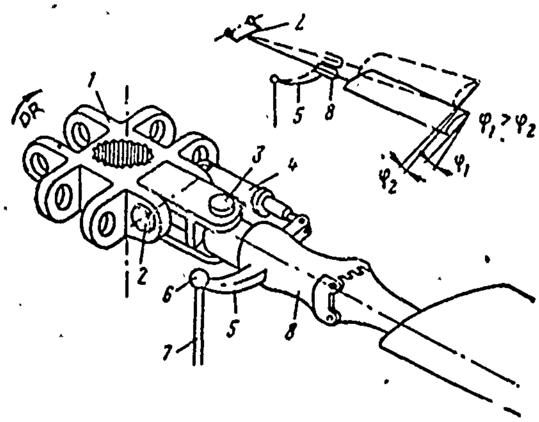

Figure 24 Diagram of Hinge Fastening of Main Rotor Blade to Hub:

1 - hub spline, 2 - horizontal hinge, 3 - vertical hinge, 4 - damper, 5 - blade pitch control arm, also acting as flap regulator, 6 - hinge, 7 - control rod, 8 - axial hinge, DR - direction of rotation. Above -- diagram of change of angle φ of blade setting when it is flapped by the flap regulator.

The presence of a vertical hinge led to the "ground resonance" phenomenon. This phenomenon is caused by the fact that when the main rotor overspeeds, the blades, rocking relative to the vertical hinge, displaces the overall center of gravity away from the axis of rotation. These augmenting

oscillations can at determined rates be equal to the natural frequencies of oscillation of the flexible system of the fuselage -- the dampening rod with its pneumatic cylinder.

The helicopter is usually more inclined toward instability when it "partially raises into the air", which is to say when the lift force of the main rotor removes part of the helicopter's weight.

A damper is included in the vertical hinge for the purpose of eliminating these oscillations relative to it.

The main rotor also fulfills the functions of longitudinal and lateral control organs.

Control of a helicopter is set up on the principle of turning equally acting aerodynamic forces. This is achieved by individually changing the positions of the blade cone by activating the control levers. When the control levers are activated, the angles of attacks of the blade are changed according to azimuth. As the result, the equally acting aerodynamic forces are inclined in the required direction.

Axial hinge 8 is introduced for turning the blade relative to its longitudinal axis.

A flap regulator is used for decreasing the flapping motion of the blade relative to the horizontal hinge. The principle of operation of the flap regulator (see Figure 24) consists of the following. Control rod 7 is connected with blade pitch control arm 5 in such a manner that the axis of hinge 6 is not located on the axis of horizontal hinge 2. With this arrangement, during flapping, the axes of these blade hinges will be turned in axial hinge 8. As the result, angle of attack φ_1 of the blade will be decreased to angle φ_2. With the angle of attack decreased, the lift force of the blade will decrease and blade movement relative to the horizontal hinge will be less. The axis of hinge 6 coincided with the axis of hinge 2, during flapping movement of the blade, there will be no decrease in the angle of attacc φ_1.

In this manner, during progressive flight, due to the effect of changing aerodynamic and inertial forces, the blades accomplish an oscillation relative to horizontal 2 and vertical 3 hinges and also turn in axial hinges 8.

The requirements stipulated for the main rotor emanate from the various of its functions mentioned above and are determined by considerations of aerodynamics, dynamics of blade movement, strength, rigidity and design weight, and also by conditions of production and operation.

Basic Requirements for the Main Rotor.

Aerodynamic Requirements:

a) Main rotor coefficient of efficiency at operating speeds and sufficiently high autorotation properties;

b) Minimum blade hinge moments to ease control of the helicopter;

c) Provisions for blade movement stability relative to all hinges.

Requirements for Strength, Rigidity and Reliability:

a) The absence of resonance type blade vibrations in all flight configurations;

b) The absence of fatique destruction in blades and hub parts;

c) Sufficient blade rigidity against lifting and bending in the plane of rotation and against bending from its own weight;

d) The blade surface must not be destroyed due to the abrasive action of rain, snow, hail and sand.

Production and Operational Requirements:

a) The capability of manufacturing blades with modern methods in large-series production;

b) Interchangability of blades;

c) Simplicity of blade fastening to the hub;

d) Convenience in balancing blades in the entire main rotor;

e) Simplicity of adjusting the main rotor and a minimum number of periodic adjustments of angles of attack of the blades, dampers and others.

Types of Main Roters

The type of a main rotor is determined by the design of the hub.

Three types of main rotors are used in helicopters:

a) Main rotors with hinged fastening of each blade to the hub (see Figure 24);

b) Main rotors on a universal joint;

c) Main rotors with "rigid" fastening of the blades to the hub.

The system of the main rotor with hinged blade fastening includes the blades, the hub with horizontal, vertical and axial hinges and blade dampers.

The main rotor on a universal joint consists of blades, the hub with a common horizontal hinge and axial blade hinges.

The main rotor with "rigid" fastening of the blades to the hubs has only the axial hinge, relative to which the blade is turned by a control gyroscope.

Forces and Moments Acting on Main Rotor Blades

The following act on blades:

1) Aerodynamic forces -- lift force in a vertical plane and the force of frontal drag in the plane of rotation;

2) Centrifugal force;

3) Forces of inertia arising due to the flapping motion of the blade relative to the horizontal hinge, from oscillation in the plane of rotation relative to the vertical hinge and from oscillation relative to the axial hinge. Besides this, Coriolis forces act in the plane of rotation;

4) The moment from the vertical hinge damper;

5) Their own weight.

With the exception of centrifugal force and their own weight, these forces are not constant during the progressive flight of a helicopter. They change periodically depending on the azimuthal position of the blade.

Changing air forces acting on the main rotor blade arise during horizontal flight. From the point of view of the appearance of vibration, the hovering mode is a quiet mode and periodic forces arising during it have a secondary character (for instance, the impulse experienced by the blades during their passage above the wing, tail boom and other parts of the helicopter).

A large part of the forces transmitted by the main rotor are periodic, repeating cyclically during each revolution. The changing forces arise as a result of changes in the flow-past speed and the angle of attack of the rotating blades.

Inclination of the main rotor cone creates a geometrical asymmetry which causes shaking of the hub. The amplitude of these oscillations increases with an increase in main rotor inclination, leading to a limit in airspeed.

Another reason for vibration caused by the hinged fastening of the blades is the flapping movement of the blades.

Not only the controls, but the entire helicopter as a whole is subjected to the effect of vibrations transmitted from the main rotor.

Vibrational forces can act in the vertical, longitudinal and lateral directions.

Decreasing vibrational impulses is generally speaking a question of the proper design of blades with consideration for the proper distribution of mass and aerodynamic forces along the blade.

To eliminate resonance oscillations when designing a blade, calculations are made to determine its natural frequencies of oscillation in bending and twisting. These frequencies are compared with frequencies of disturbing aerodynamic and inertial forces. Disagreement between these oscillation frequencies in amount and direction is a definite condition for the absence of vibration.

The main rotor must be balanced. Balancing the main rotor consists of equalizing the lift forces and hinge moments of each of the blades so that during rotation they all describe the same conic surface (rotate in the same cone), and identical hinge moments are transmitted to the control organs.

When the lifting forces are not equal, separate blades will move out of the common cone during rotation, the equally acting aerodynamic forces will be moved away from the main rotor axis and this will lead to shaking of the helicopter. During flight in this case, the pilot will sense "twitching" of the control stick. Equalization of the lift forces of the main rotor blade is basically achieved by changing the angles of blade setting by means of adjusting the lengths of the rotor control assembly rods.

Moments relative to the axial hinge (the hinge moment) depend on airspeed, tip speed of the main rotor blade, geometric dimensions of the trim tab, its location and amount of deflection, air density and other factors. They cause forces which are transmitted to the cyclic pitch control stick.

The hinge moment of a blade can be minimized by locating its axis of rotation along the axis of the centers of pressure which coincide with the axis of the center of gravity. If this is not foreseen, periodic forces will act on the controls which will tend to move the control sticks. The force acting during this on the vertical rod of the rotor control assembly will periodically deflect the rotor control assembly disc in longitudinal and lateral directions. Forces from the rotor control assembly disc are transmitted through the linkage system to the controls.

Driving the control levers may arise due to engineering errors during the manufacture of the blades, as the result of which the acutal position of the axis of the centers of pressure does not coincide with the theoretic axis. To eliminate control lever driving, small control surfaces (so-called trim tabs) which are installed on the trailing edges of the blades, are used. By bending the trim tabs upward or downward, it is possible to affect both the amount of hinge moment of a separate blade and the total forces which are transmitted from the main rotor to the control lever. Trim tabs on the trailing edges of the blades are a means for adjusting the characteristics of a main rotor.

It is possible to create cyclic warping of the blades with trim tabs and thereby adjust the flapping motion of the blade in progressive flight.

By deflecting the trim tab upward, the blade is warped in a direction so as to increase its angle of attack, the lift force of the blade is increased and blade 2 is raised upward. By deflecting the trim tab 1 downward, the blade is warped in a direction so as to decrease the angle of attack, the lift force of the blade is decreased and the blade is lowered. (Figure 25)

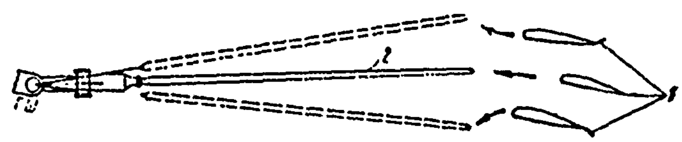

Figure 25 Effect of a Trim Tab on Blade Position Relative To the Horizontal Hinge:

1 - trim tab, 2 - blade

If during aerodynamic balancing, all blades are adjusted with the trim tabs set at a small angle downward, a large force directed away from the pilot will appear in the cyclic pitch lever.

In this case, it will seem to the pilot that the helicopter has a forward center of gravity. This phenomenon may be unnoticed during hovering, but will sharply appear during transition to a progressive airspeed, since the maximum effect of the trim tabs is present at progressive speed. At large negative (upward) angles of trim tab deviation, forces on the cyclic pitch control lever will be directed to the rear, toward the pilot and the impression of an aft center of gravity of the helicopter will be created.

In this manner, it is possible to adjust the load on the main rotor cyclic pitch control lever by deflecting the trim tabs.

Main Rotor Blade Design

A blade consists of a spar, ribs, stringers and a skin.

Rigid requirements for insuring their high reliability are stipulated for the structural elements of a blade. The blade of a main rotor is loaded with considerable dynamic loads, and therefore in the areas of maximum changing stresses in the blade, there must be no sharp changes in rigidity, rivited and bolted fastenings and other stress concentrators.

The basic structural element of a blade is the spar. The spar can be executed in the form of a round steel tube or a D-shaped profile or pressed profile out of aluminum alloy or fiberglass.

In the first helicopters, the blade spar consisted of two or three steel tubes of various diameters which were butt-connected together with bolts of sleeves. In connection with the concentration of stresses at the butt joint locations, these spars had a low strength reserve. At the present time, designers have moved to the use of a one-piece spar which is a steel tube which changes in section along its length. These spars have a significantly higher strength reserve.

Existing blade designs can be divided into the following groups: a) blades with steel tubular spars and a fiberglass or metal body and b) blades with spars pressed out of aluminum alloy or steel profiles having the form of the leading edge of the blade and fiberglass or metal trailing sections.

Blades of main rotors which are fastened to the hub on a universal joint are little different in design from blades having a hinged fastening to the hub.

Blades on universal joint suspension are loaded with high bending moments in the vertical plane and in the plane of rotation.

It is possible to eliminate the bending moment from aerodynamic and mass forces within design flight limits with design measures. With this, the blade and the hub body are installed at an angle to the horizontal plane. An angle of conicity is selected so that in the vertical plane, the sum of the moments from aerodynamic and centrifugal forces is equal to zero. In transition configurations, this quality

is destroyed, as the result of which a bending moment is present in the root portion of the blade and in the body of the hub.

Further on, we will examine designs of modern blades with a hinged fastening to the hub.

Blades with Tubular Steel Spars

Figure 26 shows the overall view of a blade from above. The basis of the blade design is the steel spar 1 which is formed out of tubing. Tip 2 and the body of the blade which consists of sections which are not connected together, root 3 and tip 7 bearings are fastened onto the spar.

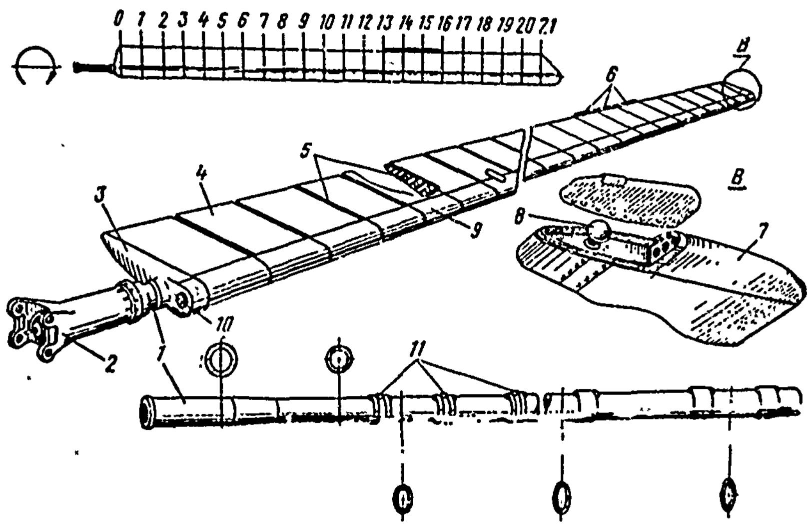

Figure 26 Main Rotor Blade:

0 - 21 -- section numbering; 1 - spar; 2 - tip, 3 - root bearing, 4 - trailing portion of section, 5 - rubber insert, 6 - trim tabs, 7 - tip bearing, 8 - contour fire lamp, 9 - leading edge of section, 10 - plug connector, 11 - clamps for fastening blade trailing sections to spar

The blade spar is manufactured of a one-piece steel cold-rolled heat treated tube having varying wall thicknesses and cross sectional shape along its entire length.

To increase dynamic strength, the external and internal surfaces of the tube are polished and cold hardened along its entire length. To prevent spar corrosion, its external surface is covered with glue and enamel and it is primed inside.

Each blade has a system for signalling damage to the spar, which consists of caps installed on the ends of the spar providing tightness of the space inside it, an air pressure signalling device which consists of a bellows sensing element filled with helium and a breather with a slide valve (charging coupling). For a better seal, clearances between the spar and the internal sections of the cap are made tight.

The cap of the spar damage signalling system is fastened on the outside end of the spar. The cap (Fig. 27) has a rubber seal 3 which insures the tightness of the inner space in the spar. The internal part of the cap 4 is drawn against the stationary part of the cap 2 with bolts 6. The cap has a conic surface which presses rubber seal 3 against the internal surface of the spar.

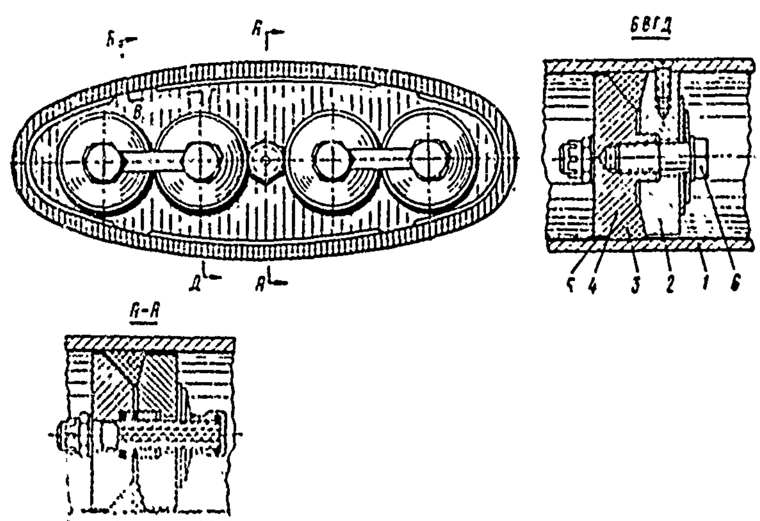

Fig. 27 Spar End Cap:
Key: 1) spar, 2) external (stationary) part of cap, 3) rubber seal, 4) internal part of cap, 5) sealing material, 6) bolt

A cap 12 which is similar in design to the end cap is also installed on the root end of the spar (Fig. 28).

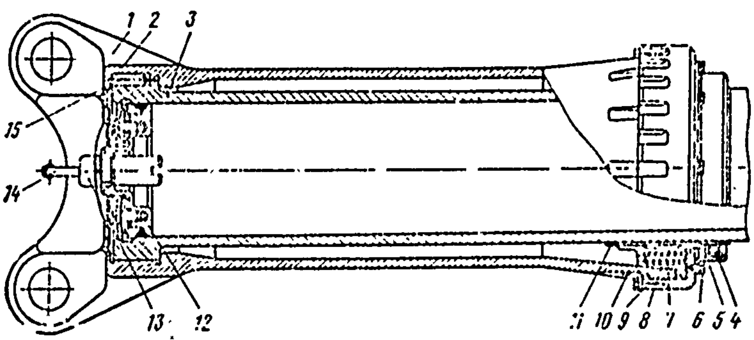

Fig. 28 Root Joint of Blade:

Key: 1) tip connector, 2) flexible ring, 3) spar, 4) rubber seal, 5) ring, 6) bolt, 7) spring, 8) slotted cone, 9) nut, 10) screw locking plate, 11) insert, 12) plug, 13) visual signal mechanism, 14) changing coupling, 15) pin

The internal space of the spar is filled with air up to a pressure exceeding the pressure necessary to begin triggering the signal mechanism. Air, reaching the signal mechanism through special holes, compresses the bellows and pulls the red cap 13 inside the body up to the marks (lines) inscribed on it.

In case cracks appear in the spar, pressure inside it and in the signal mechanism body will fall and equalize with the atmosphere. The effect of the force of flexibility and the internal pressure in the bellows, it will expand and push the red cap, signalling the loss in the hermetic seal, thereby signalling damage to the spar.

During inspection after the helicopter lands, a blade in which the pressure signal mechanism cap is protruding is removed and replaced with another one. Fatique cracking spreads in the blade spar slowly, time for appearance of

dangerous damage to the spar exceeds the normal duration of a helicopter's flight, and therefore, no air pressure signal mechanism is installed in the cockpit.

In connection with the fact that it is technologically impossible to create the root portion of the spar in such a configuration that it is possible to make eyes for transmitting forces and moments to the hub directly on it, it is necessary to have an intermediate part in the form of connector 1. The connector is designed in such a fashion that no stress concentrators are created at the place where it joins the spar.

The spar connector is manufactured of steel. Centrifugal force of the blade is transmitted to the connector by tube flange and the torque moment from the blade is absorbed by friction along the tube flange and by steel pins 15 with which the relative angular positions of the tube and connector are fixed. Axial movement of the spar relative to the connector in the direction toward the axis of the hub is limited by spring ring 2, which is installed in a circular slot in the connector.

Bending moments in the blade root are absorbed in the connector by two supports: one is along the tube flange and the second is along the girth of the tube at the end of the connector. The second support (along the girth) is accomplishhed with a slotted bronze ring 8. By tightening nut 9 of the connector, axial movement of the cone is accomplished and clearances between the spar tube 3, connector 1 and cone 8 are eliminated.

The tube is covered with a lavsan liner 11 where the bronze ring is located. This liner is bonded to the spar along the edges with glue. The faces of the liner are sealed. The lavsan liner is used for the purpose of avoiding friction corrosion during small movements of the tube relative to the connector when the blade bends.

Nut 9 is tightened with a definite moment. Loosening of the nut during operation is compensated with steel springs 7 which rest on the nut face and are located in special recesses in the bronze ring 8. Rubber seal 4 prevents moisture from entering beneath the connector.

The blade sections provide the transmittal of aerodynamic and inertial loads to the spar.

The sections are not rigidly fastened together, and therefore they are only insignificantly loaded when the blade is bent.

The formation of the trailing portion out of separate sections is explained with the following considerations: when twisting of the blade occurs due to inertial forces, the blade bends backwards in the plane of rotation and the trailing portion of the blade is in the area of compression and, therefore, the trailing stringer must either have corresponding allowable critical stresses or must not have to completely absorb the loads from compression.

From the point of view of the technology of bonding the trailing portions of the blade, it is profitable to divide them into autonomous sections so that it is easier to eliminate bonding defects and damage to trailing sections in operation by means of replacing the section which has failed.

Each section (see Fig. 26) consists of a leading 9 and trailing 4 portion. Trailing portion has a honeycomb filler. There are clearances between the sections which provide their free movement relative to each other when the spar bends. Rubber inserts 5 are installed between the sections to prevent air flowing through the clearances.

The base of the leading portion of the section is skin 1 (Fig. 29) which is made of Duralumin sheet which has a depression for laying the anti-icing boot 5. To create a rigid contour, the leading parts are bonded to their skins and diaphragms 2 and corrugated liners 3 are additionally bonded. To create the required cross sectional weight centering in the blade, counterweights are bonded to the nose parts of sections number 7 - 20 and they are additionally bonded to the skin of the leading edge in sections 7 - 14. The leading part is protected from abrasive destruction with a rubber liner.

The external contour of the trailing portion of sections number 0 - 12 and 16 - 20 is formed in a curve along the trailing edge of Duralumin skin 4 (Fig. 30). To give the trailing edge rigidity, textolite stringer 5 is bonded in it.

Sections number 13 - 15 have the trim tabs. The skin, stringer and trim tabs are bonded together and rivited into a single unit.

Reinforcing liners 2 are bonded forward on the inner surfaces of the upper and lower skins of the trailing section to eliminate sharp changes in rigidity where the skin is connected with structural section 8. The reinforcing

liners taper into an edge in the direction toward the trailing edge of the section.

The front part of the skin and liner have a slot for the skin of the leading portion of the sections. The skin and liner are bonded to honeycomb block 6 which gives rigidity to the trailing portion. The honeycomb block is bonded out of sheets of aluminum foil.

Along the sides of the trailing portions are ribs 3, whose walls are bonded to the honeycomb blocks and whose ledges are bonded to the skin and liner. Lateral liners 1 which serve for connecting the leading and trailing portions of the sections with screws are bonded to the ribs.

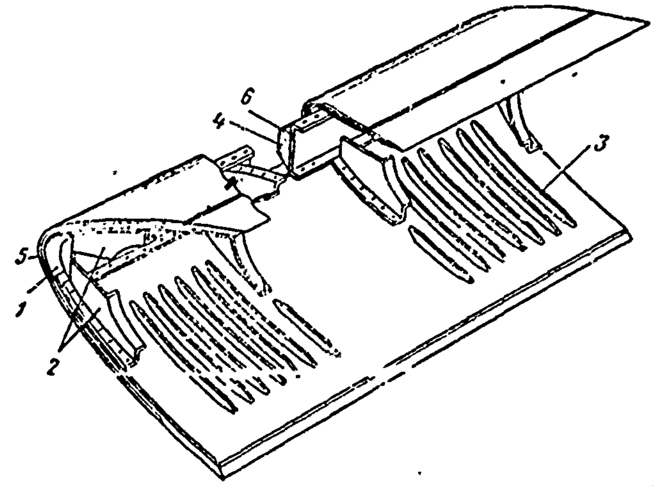

Fig. 29 Leading Edge of Blade Section:

Key: 1) skin, 2) diaphragms, 3) corrugated liner, 4) counterweight, 5) anti-icing packet, 6) channel

Shoe 7 is bonded on the front of the trailing portion. The shoes are made of Duralumin and have projecting jaws with slots in the middle which grasp the aft portion of the spar and rest against clamps which are bonded to the spar. There are holes in the top and bottom of the jaws for bolts used for fastening bands which draw the trailing portions of the sections to the spar.

To prevent moisture from getting inside the sections, all seams are bonded and the manufacturing holes in the aft portion are covered with a sealing substance.

A portion of the root bearing is bonded to the aft portion of the zero section and riveted from the root side.

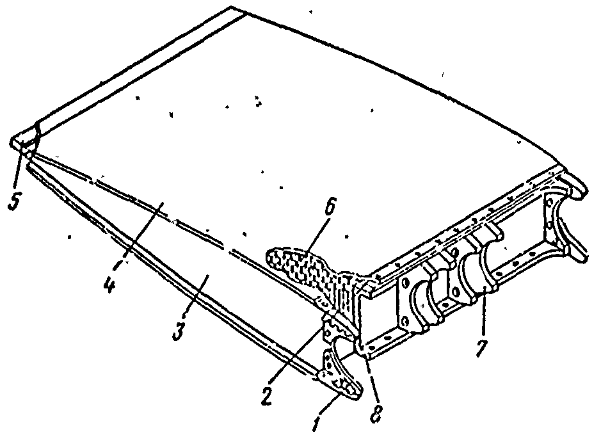

Fig. 30 Trailing Portion Blade Section:

Key: 1) lateral liner, 2) liner, 3) rib, 4) skin, 5) stringer, 6) honeycomb block, 7) shoe, 8) structural beam

Steel pins 2 (Fig. 31) are used for fastening the trailing portions of the sections onto the spar.

There are holes on shoes 1 of the trailing portions of the sections into which pins are installed and the sections are drawn against the spar by four steel bands 8 (two on top and two on the bottom). Each band is fastened to the shoe by bolts 5. During assembly of the trailing portions of the sections to the spar, the shoes are simultaneously bonded by their U-shaped surfaces to the clamps on the spar. Bands 8 which encompass the spar are drawn together by bolts through crosspieces 7 which are inserted in eyes in the bands.

Lavsan gaskets are laid between the clamps and the bands and prevent friction of the bands along the clamps. All bonded support connecting seams, the pins and the clamps with the spar, as well as the shoes with the clamps, are covered with a sealing substance.

During assembly of the blade, the leading portions of the sections are installed on the trailing portions along a groove, bonded along the entire assembly surface and fastened with screws along the trailing section shoes. The screws have countersunk heads and are installed in glue so that they cannot voluntarily back out.

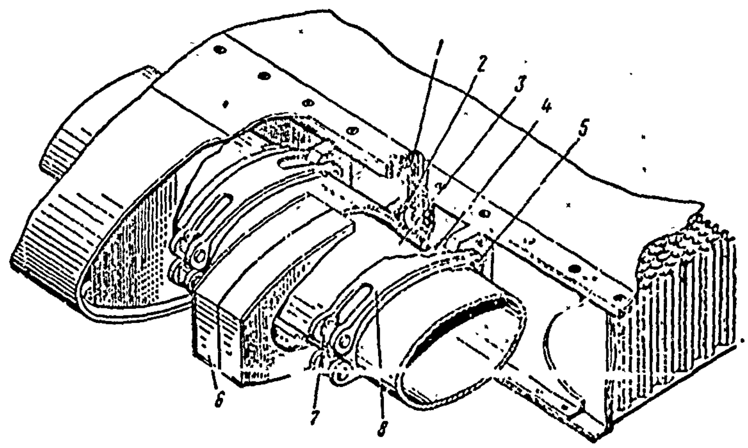

Fig. 31 Fastening of Trailing Sections onto the Spar:

Key: 1) trailing section shoe, 2) pin, 3) spar, 4) clamp, 5) bolt, 6) plastic foam block, 7) c oss-piece, 8) band

Plastic foam blocks 6 which are reinforced with plywood are bonded to the spar in the places where the middle parts of the blade sections are located, and the leading portions are bonded to them. The leading and trailing portions are connected together along the edges of each section by screws through the lateral inserts in the trailing portions.

The root fairing 3 (See Fig. 26) consists of a leading and a trailing portion which are manufactured of Duralumin. The trailing portion is bonded and riveted to the trailing portion of the zero section and has Duralumin diaphragms for rigidity. The leading portion of the fairing is connected to the tail portion and the leading edge of the first section with screws. On the root side of the blade, the fairing surrounds the spar tube in a ring. A rubber gasket is laid between them.

A bracket is installed on the spar beneath the leading portion of the fairing and a plug disconnector is fastened on it. The leading part of the fairing has holes on the root side for connecting the pug of the wire bundle to the plug disconnector.

The tip fairing consists of a leading and trailing portion (Fig. 32). The leading portion is manufactured of stainless steel and the trailing portion is manufactured of Duralumin.

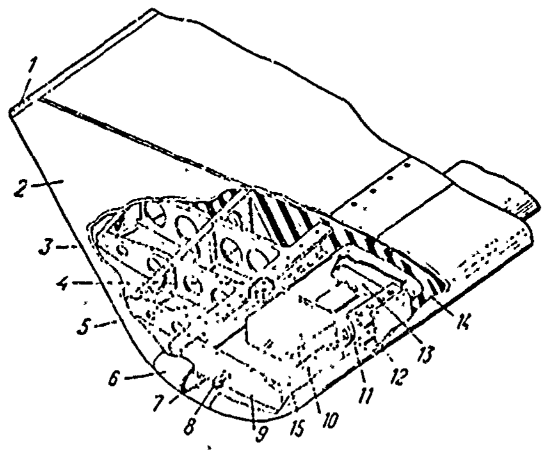

Fig. 32 Blade Tip:

Key: 1) stringer, 2) trailing portion of fairing, 3) rib, 4) structural member, 5) shoe, 6) leading portion of fairing, 7) fairing made of organic glass, 8) contour light lamp, 9) diaphragm, 10) balancing plates, 11) spar, 12) cover, 13) boss, 14) rubber insert, 15) front structural member

The trailing portion of the fairing 2 has a set of ribs 3 which provide rigidity. The ribs and skin are bonded together and riveted. A textolite stringer 1 is installed along the trailing edge of the rear portion. Shoe 5, which is fastened to spar 11 with bolts, is bonded onto the front of structural member 4. There is a groove in the front part of the rear portion in which the front part of the fairing is installed.

The front part of the fairing has diaphragm 9 for rigidity and, on the blade tip side, a port with a window made of organic glass for the contour light lamp 8.

The front part of the fairing is fitted onto the front of structural member 4 during installation on the blade and fastened to anchor nuts with screws.

At the blade tip, structural member 4 is connected to diaphragm 9, on which the contour light lamp 8 is fastened. This diaphragm is also riveted to the front structural member 15 of the leading portion of the fairing.

The skin of the leading portion of the fairing is connected with screws to structural member 4 of the rear portion, to diaphragm 9 and to the front structural member 15.

Inside the spar at its end is a steel boss 13, which is connected with two pins, closed by covers 12 on the top and bottom of the spar, which prevent them from falling out. The covers themselves are fastened to the spar with screws.

Two pins are screwed into threads in the boss and a set of steel balancing plates 10 are fastened on them with nuts. The balancing plates are necessary for equalizing the static moments of the blade in each set relative to the axis of rotation.

Blades with a Pressed Duralumin Spar

Blades with a pressed spar have a right angle form in plan since it is impossible to manufacture a pressed closed profile of changing section.

The trailing sections with their honeycomb filler (Fig. 33) are fastened with bonding material to the ledges and rear wall of the spar. The trailing sections together with the spar form the contour of the blade.

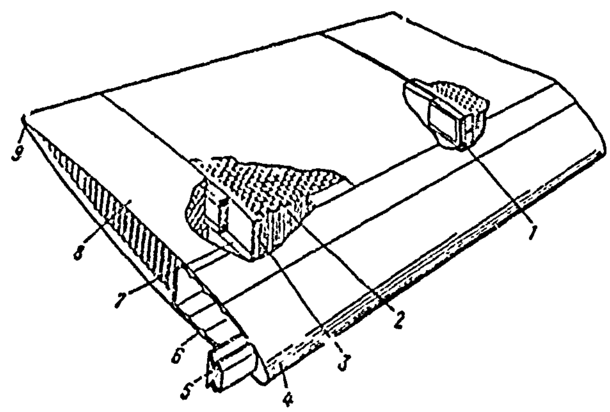

Fig. 33 Typical Section of Main Rotor Blade with Pressed Duralumin Spar:
Key: 1) inter-section rubber insert, 2) honeycomb filler, 3) tongue, 4) anti-icer, 5) counterweight, 6) spar, 7) rib, 8) skin, 9) trailing stringer

Spar 6 is a hollow beam with an inner contour of constant section. The spar is formed on the outside according to the given section of the blade leading edge profile. The interior and exterior surface of the spar are cold worked with steel balls by the vibration method.

A constant section pressed structural member of aluminum alloy is used for the initial stock while manufacturing the spar. The upper and lower flats of the spar have ribs inside to provide the necessary rigidity. The first ribs back from the leading edge serve as guides for counterweight 5.

The trailing portion of the blade is formed in separate sections. Each section is a skin, bonded with a honeycomb filler, with two lateral ribs and with a trailing edge stringer.

Air penetration between the sections is eliminated with sealing inserts.

Counterweight 5, consisting of separate sections, is inserted in the leading edge of the spar to provide the required chord-wise weight centering.

Each part of the counterweight is covered with rubber, which allows it to be tightly inserted along the front guiding rigidity ribs in the spar hollow and prevent friction corrosion.

The root part of the spar (Fig. 34) is thickened for installation on it of the connector tip which connects the blade with the hub.

The tip is fastened to the spar with bolts 2. The tip is bonded to the spar to prevent corrosion.

The end of the spar is closed with a cover. Breather 5, which is intended for pumping air into the spar hollow, is located on the cover and plug disconnect 7 is fastened to it. The cover also serves as the root end plug of the spar.

Pressure signalling mechanism 3 of the spar damage signal system is installed on the rear wall of the spar near the face of the root portion.

Fairing 5 is installed on the tip portion of the blade (Fig. 35). When the fairing is removed, access is opened to the piece fastening the counterweight 2 to

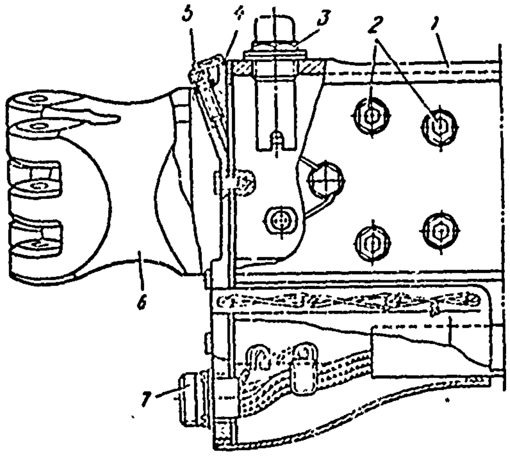

Fig. 34 Root Portion of Blade Spar:

Key: 1) spar, 2) bolts fastening tip to spar, 3) pressure signalling device, 4) spar plug cover, 5) charging breather with slide valve and wrench-cap, 6) connector tip, 7) plug disconnector

balancing plates 4 and to the contour light lamp 6. The balancing weight is fastened on two pins to the end plug 3 of the signalling system.

Blade Anti-Icing Systems

An anti-icing system of electrothermal action (Fig. 36) with electric heating elements (Fig. 37a) is installed in the leading portion of a helicopter blade. The anti-icer consists of glass fabric layers 9 and 11, rubber surface layer 10 and heating element 6 which is laid between layers 9 and 11.

The heating element 6 is made up of thin bands of stainless steel located along the entire length of the blade and bonded to the fiberglass. For protecting it from abrasive action, the insulating packet with the heating element is covered with rubber sheets 4 and 10.

The heating elements are terminated with buses 3 having wires 1, which are soldered to the plug disconnector installed at the blade root (see Fig. 37 b).

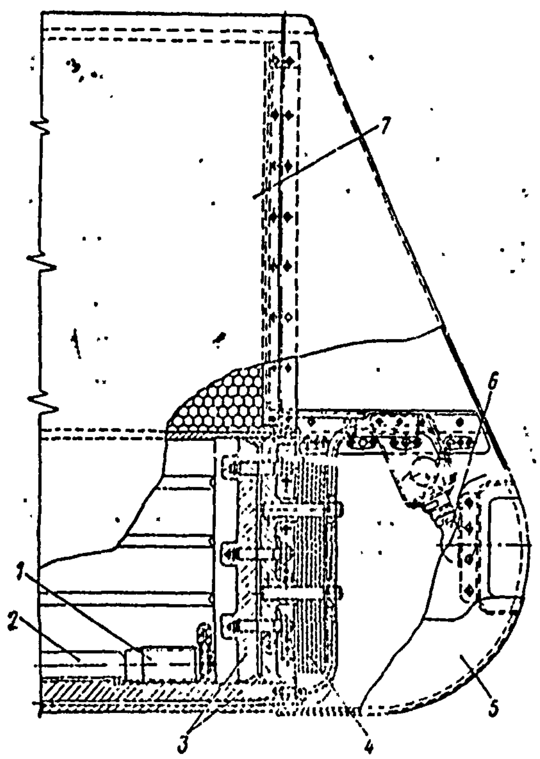

Fig. 35 Tip Portion of Blade:

Key: 1) screw support, 2) counterweight, 3) signalling system plug, 4) balancing plates, 5) removable portion of fairing, 6) contour light lamp, 7) trailing portion of section

Transmission of voltage from the on-board circuit to the blade heating elements during rotation of the rotor is accomplished with a current pickup (Fig. 38) located on the hub.

The main parts of the main rotor current pickup are the commutator 6 and brush holder 1 with the shoes 4 and brushes 9 installed on it. The commutator is prevented from rotating by a hollow rod which connects the splined bushing with a flange on the main reduction gear body.

The anti-icing system is switched on. The sections of the heating elements are switched on in order in a definite sequence, one after the other. The sequential switching-on of the sections is accomplished with a programming mechanism.

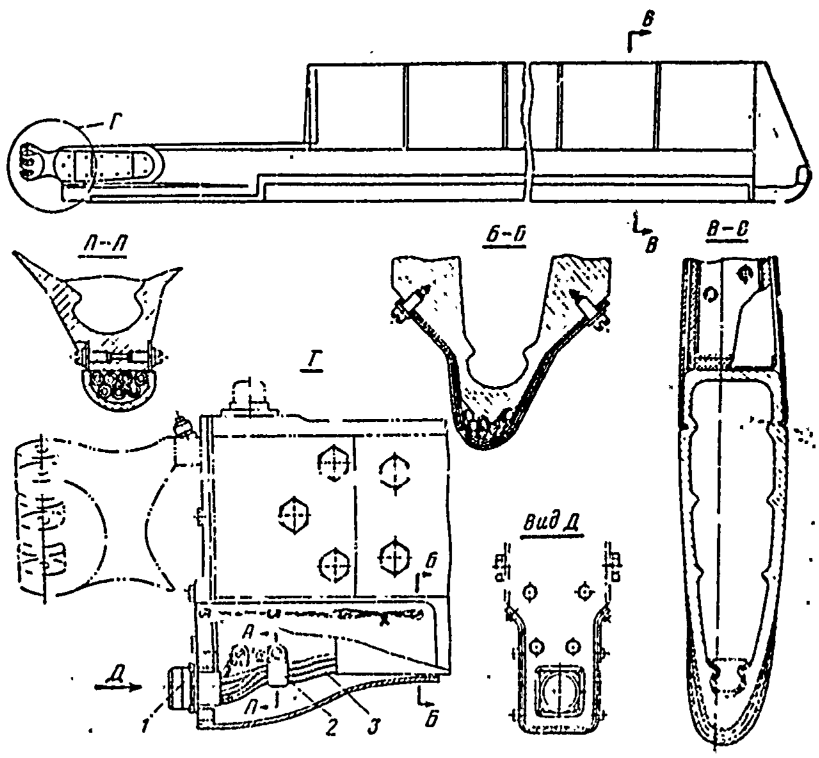

Fig. 36 Anti-Icing Installation of Main Rotor Blade:

Key: 1) plug disconnector, 2) binding clamps, 3) wire

Control over the operation of the blade anti-icers is accomplished with a volt meter which shows the voltage in the alternating current circuit and with an ampmeter having a switch which changes the force of the current in all sections of the elctric heaters.

An icing signal mechanism is installed on the helicopter to transmit a signal indicating the beginning of icing. The signal mechanism, with a sensor and tracing block, automatically engages the rotor anti-icers, the front windshield and the fairings of the intake devices of the engines.

The sensor is a cylinder, on the surface of which are located two rings having a clearance between them. These rings are included in the electric circuit of the tracing block layout.

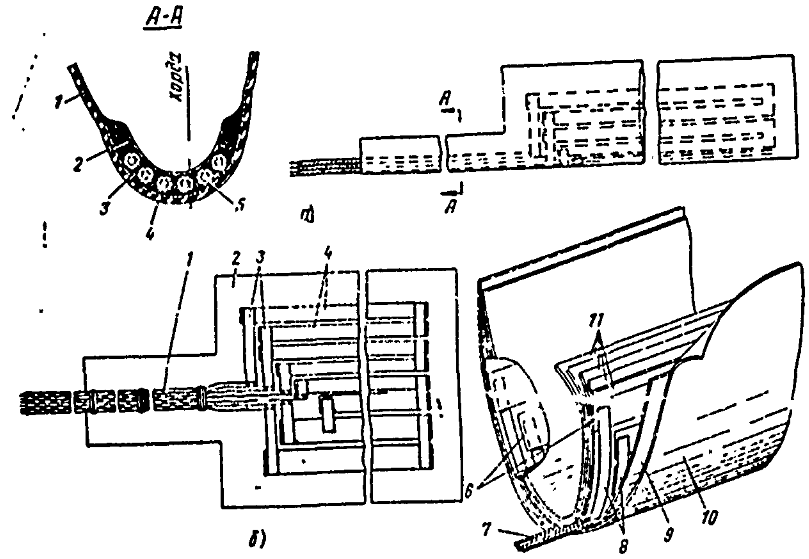

Fig. 37 Electric Heating Elements of Main Rotor Blade:

Key:

a) main rotor blade heating lines:
    1 and 2, glass fiber layers
    3, rubber
    4 and 10, rubber surface layer
    5 and 7, wire
    6, heating element
    8, connector bars
    9, external glass fiber layer
    11, internal glass fiber layer

b) main rotor blade heating element:
    1, wire
    2, insulating packet
    3, connecting bars
    4, heating element

The basic element of the tracing block is a thyratron. Positive voltage is transmitted to the circuit of the thyratron through the closing rings of the sensor.

When the helicopter enters icing conditions, supercooled droplets of water, settling on the surface of the sensor, are transformed into ice which fills the clearance between the rings. The electric circuit of the sensor becomes closed and positive voltage is transmitted to the

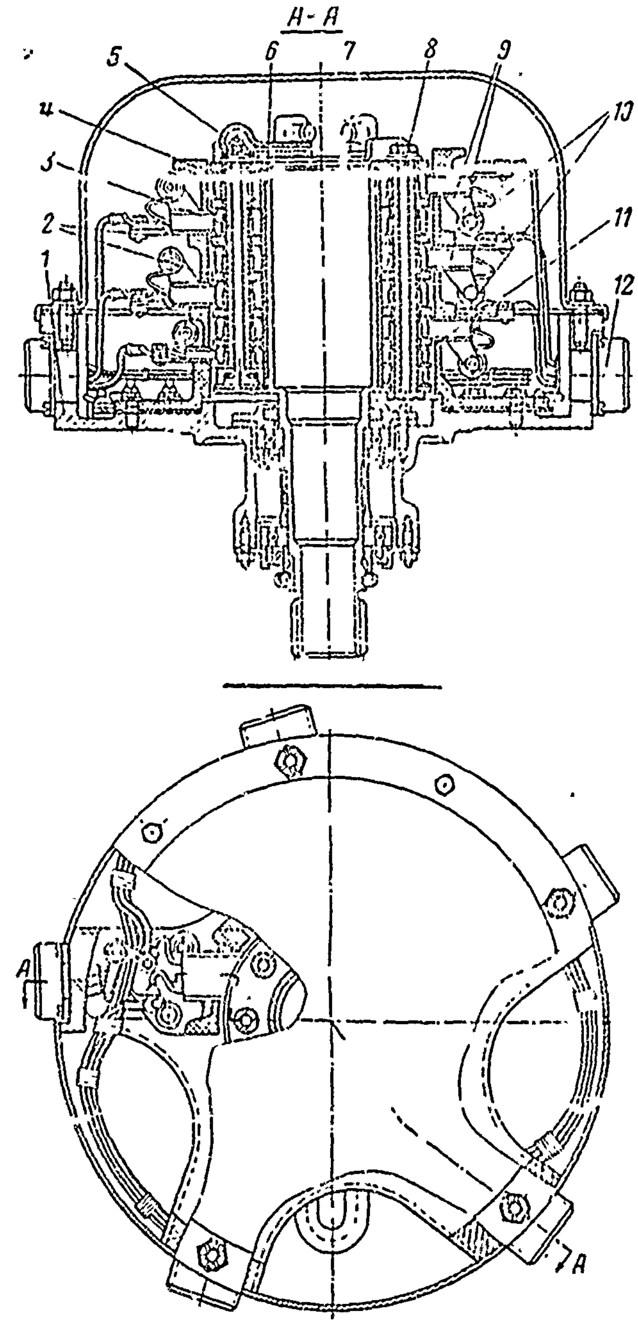

Fig. 38 Main Rotor Current Pickup:

Key: 1) brush holder body, 2) insulating rings, 3) contacts and bolt for brush shoe, 4) brush shoe, 5) rubber boot, 6) commutator body, 7) current pickup cover, 8) tension bolt, 9) brushes, 10) pressure springs, 11) contact rings, 12) plug disconnector

thyratron circuit along this circuit, as the result of which electric current flows through the thyratron. A relay is included in the anode circuit of the thyratron and voltage from the on-board circuit is simultaneously transmitted through the closing contacts of it to the signal lamp in the "turn-on anti-icing system" panel, to the anti-icing automatic engagement diagram and to the heating element of the sensor. When the anti-icing system is turned on, current is fed to the signal lamp of the "anti-icing system on" light panel.

After icing has stopped, the anti-icing system is turned off manually by pressing on a button installed on the anti-icing system panel.

In addition to the electric sensor, a visual icing sensor is installed on the helicopter. This is a rod which is installed so that it is easily seen by the left pilot. Red and black lateral stripes are painted on the rod. These stripes provide the possibility for the pilot to see the growth of ice on the rod during icing. In case the signal mechanism fails, the pilot, using the visual sensor, engages the anti-icing system.

Main Rotor Hub Design

With mechanically driven main rotor blades, the torque moment is transmitted from the engine through the hub. The hub absorbs aerodynamic and inertial forces and moments arising on the main rotor blades and transmits them to the fuselage.

The most widely used hub layout is that of the hub with articulated blade fastening (Fig. 39).

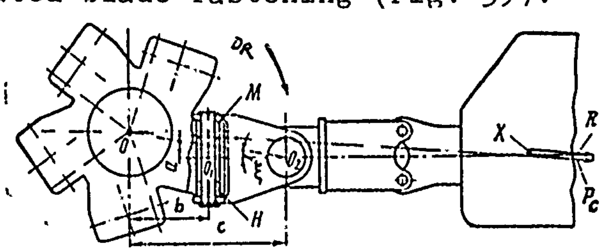

Fig. 39 Diagram of Blade Hinge Location:
Key: O -- axis of rotation; O_2 -- axis of vertical hinge; a -- movement of hub body eye center from axis of rotation; b -- displacement of horizontal hinge; c -- displacement of vertical hinge; M, H -- needle bearings; ξ -- angle of rotation of horizontal hinge relative to radial direction; R -- equivalent force; P_c -- centrifugal force; X -- frontal drag force

The hub has spaced horizontal hinges, and also vertical and axial hinges. Similar articulation of blades with the hub gives them the possibility of oscillating relative to the horizontal and vertical hinges.

The horizontal hinges allow the blades to accomplish a flapping motion (oscillation in a vertical plane) due to the effect of aerodynamic forces which change in azimuth.

The vertical hinges provide the possibility for the blades to accomplish oscillation in the plane of rotation. These oscillations take place due to the effect of the changing forces of frontal drag and the Coriolis force of inertia.

Changing stresses in the elements of the main rotor are significantly reduced due to the articulated fastening of the blades with the hub body.

Oscillations of the blades relative to the vertical hinge are damped with hydraulic dampers.

Axial hinges on the hub are intended for changing the angles of blade setting.

The hub is designed in such a manner that when the blade flaps relative to the horizontal hinge, a decrease in the angle of blade setting takes place.

Needle bearings M and H of the horizontal hinge are located symmetrically relative to the perpendicular $O_1 O_2$, dropping from the center O_2 of the vertical hinge to the shaft of the horizontal hinge.

The centers of the eyes of the hub body are displaced by distance a from the axis of rotation. With this location of the eyes, the horizontal hinge is a turning one relative to the radial direction by angle ξ

Angle ξ is selected with such a magnitude that at the primary flight regimes, the equivalent aerodynamic and centrifugal forces R on the blade are directed along the $O_1 O_2$ line. This provides a more equal distribution of loads between the needle bearings of the horizontal hinge and essentially increases their longevity. The axial force absorbed by the support bearing of the horizontal hinge is simultaneously decreased. The major parts of the main rotor hub (Fig. 40) are the hub body 5, brackets 6, axial hinge pins 9, axial hinge body 29 and blade turning lever 83.

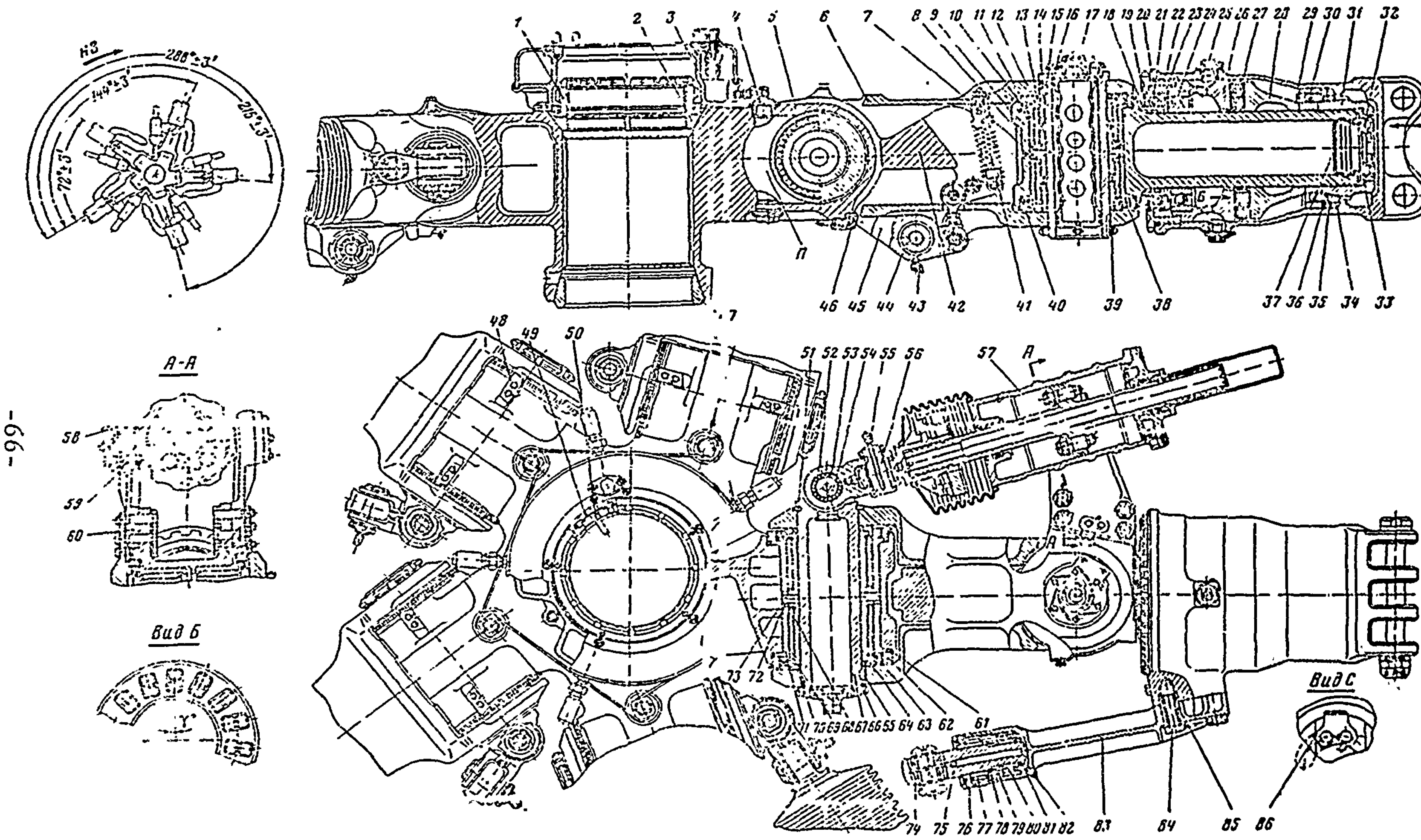

Fig. 40 Main Rotor Hub   Key on following page

Key to Fig. 40:

1) shaft nut, 2) upper cone, 3) hydraulic damper reservoir, 4) plug, 5) hub body, 6) bracket, 7) vertical hinge support washer, 8) washer, 9) axial hinge pin, 10) nut, 11) outer bearing race, 12) inner bearing race, 13) ring, 14) sealing ring, 15) vertical hinge pin, 16) cup, 17) plug, 18) ring, 19) cup, 20) sealing ring, 21) cup, 22) axial hinge nut, 23) oil deflecting ring, 24) radial ball bearing, 25) plug, 26) spacing bushing, 27) roller bearing, 28) support ring, 29) axial hinge body, 30) radial ball bearing, 31) nut, 32) stop, 33) adjusting ring, 34) adjusting ring, 35) plate spring, 36) washer, 37) plug, 38) collar, 39) vertical hinge pin nut, 40) sealing ring, 41) spring, 42) spring, 42) counterweight, 43) lubrication fitting, 44) limiter shaft, 45) limiter, 46) lower support, 47) lower cone, 48, 49) locking plates, 50) locking pin, 51) slotted ring, 52) link, 53) needle bearing, 54) pin, 55) lubrication fitting, 56) link pin, 57) hydraulic damper, 58) nut, 59) needle bearing, 60) bracket, 61) sealing ring, 62) nut, 63) cuff, 64) horizontal bearing race, 65) key, 66) nut, 67) horizontal hinge pin, 68) needle bearing inner race, 69) sealing ring, 70) needle bearing roller, 71) needle bearing outer race, 72) bronze washer, 73) support washer, 74) bearing, 75) shaft, 76) cover, 77) roller bearing, 78, 79) spacing bushings, 80) ball bearing, 81) nut, 82) lubrication fitting, 83) blade rotating arm, 84) bolt, 85) bushing, 86) locking plate

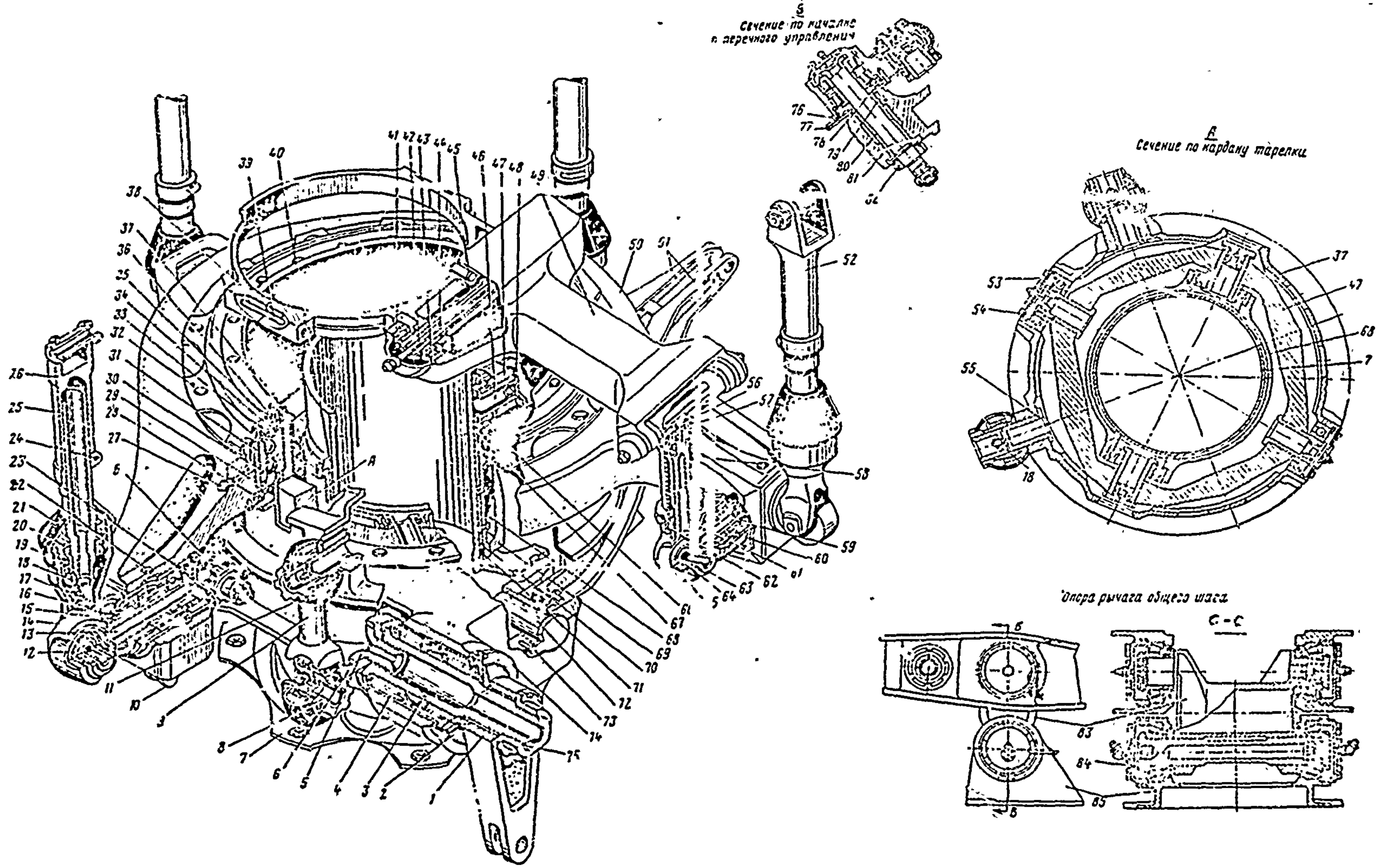

Fig. 106 Rotor Control Assembly:
[key on following page]

Key for Fig. 106:

1) rocker fork, 2) seal, 3) shaft, 4) bushing, 5) screw, 6) longitudinal direction rocking lever, 7) guiding slide, 8) pin, 9) rod, 10) lateral direction rocking fork, 11) rubber cap, 12) ball bearing, 13) shaft, 14) lower rod end, 15) ring, 16) rubber ring, 17) cover, 18) nut, 19) ball bearing, 20) nut, 21) rubber cap, 22) grease fitting, 23) cup, 24) bolt, 25) rod shaft, 26) rod upper end, 27) grease fitting, 28) body, 29) collar, 30) bearing, 31) bushing, 32) flange, 33) collar, 34) ring, 35) shield, 36) nut, 37) universal joint outer race, 38) shrinkage bracket, 39) bolt, 40) collar, 41) nut, 42) pin, 43) cover, 44) shaft, 45) pin, 46) pin, 47) universal joint inner race, 48) nut, 49) warping link, 50) plate, 51) lever, 52) blade turning rod, 53) cover, 54) pin, 55) pin, 56) grease fitting, 57) nut, 58) warping lever, 59) nut, 60) body, 61) rod end, 62) nut, 63) pin, 64) needle bearing, 65) shaft, 66) ball bearing, 67) bronze bushing, 68) slide, 69) slide bracket, 70) bronze bushing, 71) collar, 72) pin, 73) bolt, 74) longitudinal direction scale, 75) nut, 76) lateral direction scale, 77) disc, 78) pin, 79) pin, 80) bushing, 81) shaft, 82) nut, 83) link, 84) pin, 85) bracket, A) section across plate universal joint, B) section across lateral direction rocker, C-C) collective pitch support lever

Hub body 5 is linked with the main reduction gear shaft by evolute lines and centering cones: the lower one 47 -- a bronze with one cut, and an upper one, 2 -- a steel one consisting of two halves.

The body is fastened onto the shaft with nut 1, which is locked by hinge 50. The body has five (according to the number of blades) eyes, which form the horizontal hinges in connection with bracket 6.

There is a hollow space inside each eye of the hub body where oil is poured for lubricating the horizontal hinge bearings.

The outer ring installation 71 of the needle bearings in the hub body provides constant lubrication to the most stressed needles even when the hollow is only partially filled with oil.

Oil is poured into the eye hollow through plug 4. Oil is drained through drain holes which are closed with plugs. Each eye has upper and lower supports which limit the flapping motion of the blades. Lower supports 46 are made removable so as to allow their replacement in operation in case cold hardening or other defects appear.

There are holes in the lower portion of the body to locate the warping link bracket of the rotor control mechanism plate.

The needle bearings of the horizontal hinge consist of outer and inner rings and a selection of needles. The outer rings 71 are fastened in the body with nuts 62. The nuts are locked with plates 48 which are bent against the body. Inner rings 68 of the bearings, rings 64 and 71 are assembled on pin 67 of the horizontal hinge and compressed between the eyes of the bracket by nut 66. The pin rests on the bracket with slotted ring 51 and is prevented from rotating by key 65. The inner hollow of pin 67 is sealed off from moisture on the side of the slotted ring with a rubber plug and on the opposite side with a plug having an eye intended for mooring the blades.

Bronze washers 72 are located between the outer rings of the needle bearings and the support washers 73, and absorb axial loads arising during deflection of the blades from a direction perpendicular to the axis of the horizontal hinge.

Sealing of the horizontal hinge is achieved by stationary rubber rings 61 and 69 and reinforced collars 63. Collar 63

has an additional band for protecting its main working edges from dust and premature wear.

Bracket 6 is a box section part. There are eyes on the pins of the bracket which are intended for connecting it with the hub body 5 and axial hinge pin 9. The connect brackets form the vertical hinge with the pin.

The construction of the vertical hinge is similar to the construction of the horizontal hinge. Cup 16 is fastened on the upper part of pin 15. Plug 17 covers the hole through which oil is poured into the cup.

Oil flows to the needle bearings through drilled holes in the cup and pin. For full elimination of air, a grease fitting is screwed into the lower cup and grease is forced through it during assembly. When the grease is forced in, it passes through the hole in the lower outer ring 11 to the needle bearings, forcing air out through the by-pass valve located on the pin support. Lubricant is poured immediately into cup 16 through a filler plug.

The axial hinge consists of two major parts; pin 9 and body 29. On the pin are two flanges for fastening brackets 60 of the hydraulic damper, rigid support-limiters of blade rotation around the axis of the vertical hinge and an inner cylindrical hollow for assembly of the needle bearings of the vertical hinge. The pin has a tail portion with threads, on which are installed and fastened the bearings of the axial hinge: a support roller bearing which absorbs centrifugal forces and two ball radial bearings which absorb bending moments transmitted from the blades.

The recesses of the support roller bearing retainer are located at angle γ. Due to this location of the recesses, during rocking motion, the bearing retainer not only oscillates together with the movable ring, but also turns in one direction.

The constant movement of the retainer during the rocking motion leads to a sharp decrease in the number of repeated stresses experienced by different elements of the paths of rocking. The longevity of the bearing is significantly increased due to rotation of the retainers.

During assembly on the pin tail, the following are mounted in sequence: nut 22 with collars, oil deflecting ring 23, radial ball bearing 24, spacing bushing 26, roller bearing 27, support ring 28 and radial ball bearing 30. The nut is locked with stop 32, an ear of which fits in a slot in the face of the pin. The stop is in turn fastened to the nut with two bolts.

Adjusting ring 34, two plate springs 35 and washer 36 are installed in the body of the axial hinge, and then the tail of the pin with the bearing fastened on it is inserted in the body. The entire assembly is compressed by nut 22, which is locked by a plate which is bent against the body of the axial hinge.

Preliminary interference of the support roller bearing 27 in combination with the radial bearing 24 is accomplished by selection of an adjusting ring 23. Plate springs 35 create the preliminary interference of the radial bearing 30. There are holes in the body of the axial hinge for filling and draining oil. These holes are closed by plugs 25.

Sealing of the axial hinge is accomplished by stationary rubber rings 20 and collars 19 and 21.

Collar 19 protects the main collar 21 from dust and dirt, preventing the working edges of this collar from wearing excessively.

The working edges of the collar move along the surface of support ring 18. The support ring is an intermediate part which protects the surface of the tail portion of pin 9 from damage if abrasive particles fall beneath collar 19.

The support ring is pressed onto the tail of the pin and prevented from rotating by two plates which are bent against the pin on top and on the bottom.

The body of the axial hinge is made in the form of a cup, on the bottom of which is a crest with eyes for fastening the blades. On the other end of the cup is a thread for nut 22 and a flange to which the blade turning lever 83 is fastened with four bolts. The bolts 84 are relieved of the shear forces by bushing 85.

Shaft 75 with two-roll bearings 80 and roller bearing 77 are mounted on the end of the blade turning lever. Cover 76, which is tightened to the face of the lever with four bolts, prevents the shaft from moving in an axial direction.

Grease fitting 82 for lubricating the bearings is screwed into the lever. A pin connecting the blade turning lever with the rotor control mechanism rod is installed on two bearings 74 in eye of shaft of 75.

Rotation of the blade in the horizontal hinges on the hub body is limited by the upper and lower stationary supports.

In order to limit blade droop when the main rotor is not working or at low revolutions, a centrifugal droop limiting mechanism is installed in a bracket.

The centrifugal droop limiting device is shown in Fig. 41. Counterweight 1 is suspended in a bracket on pin 2 and is fastened through rod 4 with one end of limiter 6. The axis of rotation of limiter 6 is pin 5, which passes through the eye of the bracket. The other end of the limiter serves as a support which limits drooping of the blade.

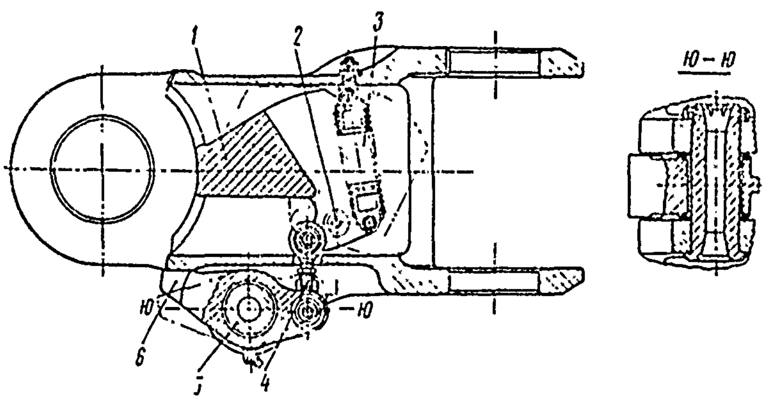

Fig. 41 Diagram of Centrifugal Droop Limiter:

Key: 1) counterweight, 2), 5) pins, 3) spring, 4) rod, 6) limiter

When the main rotor is turning less than a definite number of revolutions, spring 3 supports the limiter and the counterweight. When the number of blade revolutions increases, the counterweight turns due to the effect of centrifugal force, spring 3 is stretched and the limiter is turned. The limiter moves away from the bracket. A clearance is formed between the body support and the limiter, and blade droop is limited only the stationary supports of the bracket, allowing it to deflect downward at a large angle.

When rotation speed is decreased, the reversed movement of the mechanism begins until it returns to its original position.

Damping of blade oscillations relative to the vertical hinges is accomplished with hydraulic dampers. Differing

from friction dampers, hydraulic dampers have more stable characteristics and a lower weight.

The construction of a hydraulic damper is shown in Fig. 42a. Cylinder 21 of the huaraulic damper is installed with two pins in needle bearings which are assembled in brackets. The brackets are connected to the pin flanges with bolts.

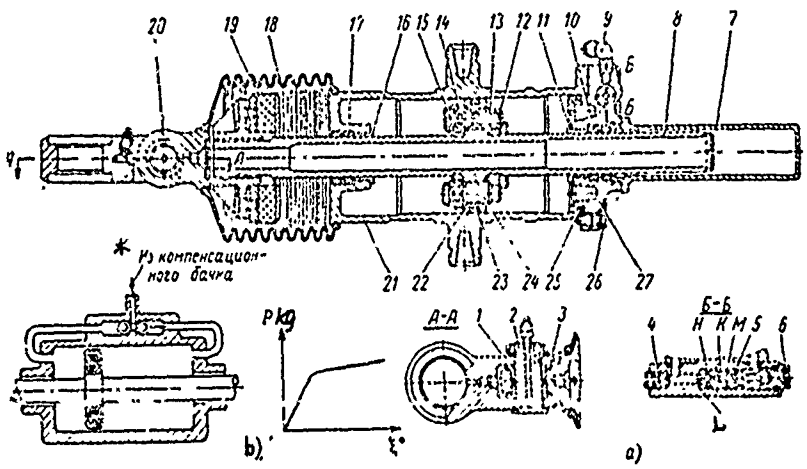

Fig. 42 Hydraulic Damper:

Key: a) plan, b) characteristics at a constant number of oscillations; 1) bronze bushing, 2) pin, 3) sealing ring, 4) plug, 5) valve, 6) plug, 7) cup, 8) rod, 9) fitting, 10) sealing ring, 11) bronze bushing, 12) valve body, 13) valve, 14) spring, 15) nut, 16) bronze bushing, 17) sealing ring, 18) boot, 19) shock absorber, 20) body support, 21) hydraulic damper cylinder, 22) polyfluoro-ethylene resis ring, 23), 25) sealing rings, 24) valve, 26) bolt, 27) cover: P) force along the rod, angle ξ of blade deviation relative to the vertical hinge, * from compensator tank

The hydraulic damper cylinder is closed on one end with cover 27. Bronze bushings 11 and 16 are pressed into the bottom of the cylinder and into the cover and rod 8 which is formed in a single unit with the piston, moves through them. In the middle portion of the rod are four by-pass

valves 24 -- two on each side of the piston. The piston is fitted with an oil sealing ring 23 which is protected by polyfluoroethylene resin rings 22 on both sides.

By-pass valve 24 consists of body 12, valve 13 and spring 14. The spring, resting on nut 15, presses valve 13 against the seat of body 12.

Support body 20 is screwed onto the threaded end of the rod and shock absorber 19, which consists of two steel plates with rubber vulcanized to them, are fastened with bolts to the support body.

The shock absorbers intended to soften shock on the rear limiter of the vertical hinge when the main rotor is started.

Boot 18 is fitted on support body 20 and cylinder 21 and protects the hydraulic damper rod from dirt. Sealing of the rod is provided by rubber rings 10 and 17 which are located in grooves of cylinder 21 and cover 27 between polyfluoroethylene resin rings. Cover 27 is sealed with a rubber ring 25, and cup 7 which closes the hole in the end of the rod is fastened to the cover.

Cover 27 of the hydraulic damper has a recess in which the compensator valve 5 is located. Passage "L" on the outside of the body of compensator valve 5 is connected with an exhaust fitting. Four holes connect this slot with the inner passage of the valve body in which three balls are located: two large ones "M" and "H" and one small one, "K".

The passages behind balls "M" and "H" are connected with both hollows of the cylinder.

In that the balls are "floating" ones, when the hydraulic damper is not working, both hollows of the cylinder are connected with slot "L". Slot "L" is connected through a fitting and hose with the compensator reservoir, which is fastened on the upper portion of the hub body and serves for filling streams of liquid and exhausting air bubbles from the hydraulic damper cylinder. Due to this, air is not accumulated in the hydraulic damper; at high temperatures excess liquid freely flows into the compensator reservoir.

When the damper is working, one of the balls ("M" or "H") is pressed by oil pressure against the seat of the body, disconnecting the compensation reservoir from the high pressure space and pressing the second ball ("N" or

"M") through ball "K" away from the seat. During this, the low pressure space remains connected with the compensation reservoir. Such a system provides the reliable and failure-free operation of the hydraulic damper. The compensation system is drained through a hole in the compensation reservoir body.

Fig. 42b shows the principal diagram of a hydraulic damper and a diagram of the dependency of force P along the rod on the amplitude of oscillation (angle of blade deviation) ξ relative to the vertical hinge. At small angles ξ, force P is directly proportional to the amplitude of oscillation.

A further increase in the amplitude of oscillation will lead to a relatively small change in force along the rod, since a significant portion of the liquid stream passes through by-pass valves in this case.

Section 3

Wings

Purpose of and Requirements Outlined For Wings

Wings are used not only on airplanes but also on helicopters. A stationary wing of small dimensions is an additional load-bearing surface of a helicopter of lateral design, where it not only fulfills the role of a construction supporting the main rotors but also creates additional lift force. There are helicopters of single-rotor and longitudinal designs with a stationary wing, as well as combination helicopters which can achieve high horizontal airspeeds due to a wing together with a tractor propeller. A wing installed on a helicopter increases its aerodynamic quality during horizontal flight, removing stall from main rotor blades at high airspeeds. Besides this, helicopter wings are convenient for locating fuel tanks and equipment in them, and also for locating retractable landing gear, due to which room in the fuselage is freed for locating usable payload.

The form and construction of a wing must satisfy requirements of aerodynamics, strength, engineering capacity and operation.

The aerodynamic requirements lead to the minimum interaction of the main rotor and the wing during hovering. The wing must have a high aerodynamic quality during cruise flight, have effective mechanization for obtaining the necessary lift at a corresponding rate of flight, must possess the necessary torsion strength and must fully satisfy the requirements of the norm for strength.

The designer must strive for maximum usage of each kilogram of material comprising the weight of the wing. The weight characteristic is one of the basic indices of perfection in wing design.

Design Elements of a Wing

A wing is a beam which is loaded with distributed and concentrated for s and consists of right and left cantilevers which are symme   ally located along the sides of the fuselage and the center section (center section beam).

The force schematic of a wing consists of longitudinal and lateral elements and a skin (Fig. 43).

The longitudinal elements include spars and stringers and the lateral elements include ribs.

The air load is absorbed by the skin, transmitted to the ribs and to the walls of the spar.

For instance, the ribs attempt to move upward due to the effect of the vertical components of air loading. The wall s of he spars prevent this. As a result, distributed touching forces arise in the walls of the spars. In a general case, the line of action of theequivalent touching forces does not coincide with the line of action of the equivalent air loads. As a result, the ribs attempt to turn, equalizing . . . . . [Translator's note: Pages 64 and 65 of the original text missing.]

The bands of beam spars are made of special forms whose sections differ widely (see Fig. 45b).

These forms are usually manufactured of chromansil, alloys of aluminum, titanium and other materials with corresponding treatment. The areas of spar band sections decrease along the length of the wing due to conditions of equal strength. This is accomplished by milling the bands or by means of transferring to other shapes.

Tapered inserts of aluminum alloys, textolite and other materials are used when connecting the bands with curved sections of the wing's skin (see Fig. 45c). Normal stresses of tension and compression arise in the spar bands due to the action of bending moments. Under tension, the bands are destroyed by tension less than the temporary resistance of the material σ_t. This is explained by the weakening of the section due to the concentration of stresses at the holes for rivets and bolts.

When the bands are working under compression, their destruction may occur due to an overall or a localized loss of strength at stresses less than σ_t.

Loss of strength in the bands of a beam spar is improbable due to the fastening of the spar and skin onto their walls.

Loss of strength in a thick wall under shear will lead to its destruction. After a strength loss, a pthin wall will continue to work. The understanding of a thin or thick wall (skin) depends on the size of its relative dimension (b/δ), where b is the wall width and δ is its thickness. If b/δ is such that the wall (skin) loses strength at stresses less than the limit of proportionality, it is called thin, and if it loses strength at stresses greater than or equal to the limit of proportionality, it is called thick.

Special uprights 1 are fastened to the wall of a spar for the purpose of increasing the critical stress under shear. The flanges of rib 2 (Fig. 46) are the same sort of fastened-on uprights. In panel assembly, spar wall may be formed with span- wise cuts with their consequent connection by angles 3.

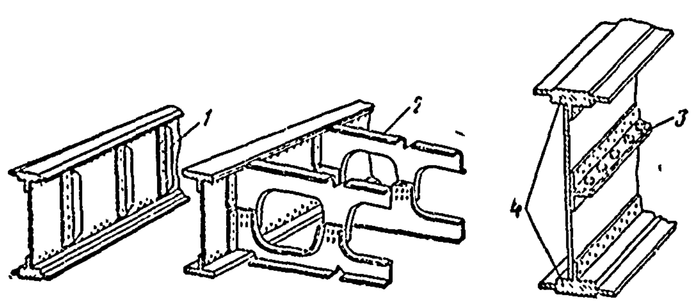

Fig. 46 Methods of Fastening Spar Walls:
Key: 1) special upright, 2) flanged rib, 3) butted angle, 4) spar bands

Stringers

Together with the skin, stringers are loaded with axial forces of tension and compression. Stresses arise as the result of lateral bending of the stringers from an air load.

Stringers both in the form of shapes which are pressed or rolled out of bars or beams and in the form of shapes which are bent or rolled out of sheets are used in wing design. The forms of stringer sections (Fig. 47) are distinguished by their wide variety. The wise choice of a stringer form is determined by manufacturers, including the relative thickness of the wing and the technology of assembly. Profiles of closed sections possess high critical stresses of local and total strength.

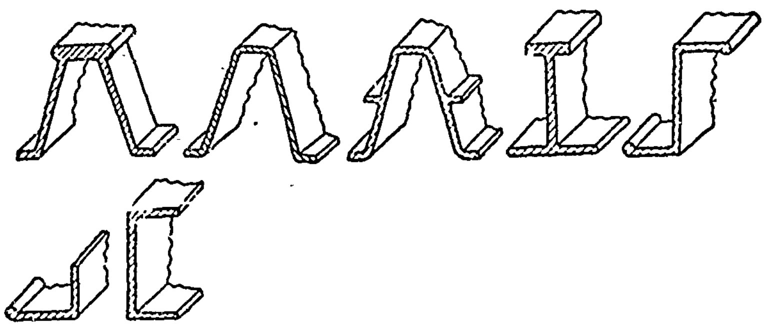

Fig. 47 Typical Stringer Sections

In stringers located in the extended area of the wing, destruction occurs under stresses close to that of temporary resistance (σ_t) and in stringer located in the compression zone of the wing, destruction can occur as the result of total or local strength losses.

The Skin

The skin of wings is manufactured out of separate sheets of duralumin, titanium alloys and other materials. The sheets of the skin may be connected together with riveted and bonded seams located, as a rule, above the members of the longitudinal and lateral construction elements.

Normal and tengential stresses arise in the skin due to the total bend and twisting of the wing Normal and tangential stresses of lateral bending from local air loads are insignificant. The strength of the skin, depending on its parameters, is determined by the amount of normal stresses of compression or tension or by the amount of tangential stresses.

Ribs

According to their purpose and design execution, wing ribs are divided into two types -- normal and reinforced.

Normal ribs serve to maintain the given form of the wing profile, transmit aerodynamic load to the spar and skin and take part in the total work of the wing, fastening the skin and the structural elements.

Reinforced ribs fulfill the same functions as normal ones, and also serve to absorb concentrated forces from fastening various assemblies. Besides this, reinforced ribs are inserted at the edges of large cuts, at disassembly points and other places where they are subjected to considerable loads, participating in the redistribution of forces among the elements of the wing.

The major loads for normal ribs are distributed aerodynamic forces. Normal ribs can be viewed in a force relationship as beams which work under bending in a vertical plane, bringing the tangential stresses of the skin and spar walls, with which they are usually fastened, into equilibrium.

Typical normal ribs are executed in the form of solid walls of a sheet material (Fig. 48a). These ribs are called beam ribs. Their bands can be formed by flanges of the walls together with the skin sections lying against them or by special forms. According to the conditions of strength, rib walls are often very thin. This creates difficulty in accomplishing high-quality riveted seams and other types of connections. Therefore, the design thickness of the walls is increased, but holes or localized thin places are made by, for instance, the method of chemical etching for the purpose of decreasing weight. To increase critical stresses of the walls under shear, special stands are sometimes fastened to them or ridges are stamped on them.

Ribs consisting of two halves which are not connected together (Fig. 48b) are sometimes used for the purposes of

simplifying wing assembly and improving its quality. These are called frame ribs. Differing from beam ribs, they are less usable in a weight relationship. This is explained by the fact that each half of the frame rib works under bending independently, by a two-band beam.

In places where the fuel tanks are located, the ribs are formed without walls (Fig. 48c).

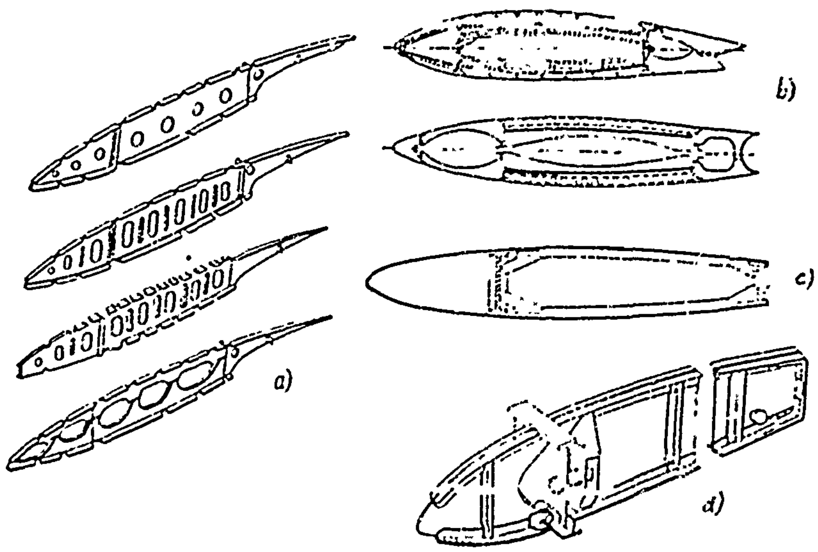

Fig. 48 Ribs:

Key: a) typical normal ribs, b) frame ribs, c) two-band rib, d) reinforced rib

The construction of reinforced ribs is largely similar to that of normal ribs (Fig. 48d). However, their center parts and sometimes their leading edge are highly developed and are reminiscent of wing spars in section.

Disassembly and Butt-jointed Parts

Depending on the degree of participation of their power elements in absorbing bending, design forms of wings can be divided into spar-type and monoblock. Spar-type constructions include those in which the bands of the spars absorb the major portion of the bending moments, and the comparatively thin, weakly fastened skin primarily works to absorb the twisting moments and lateral forces.

In monoblock wings, longitudinal forces from bending are absorbed by the skin together with the elements fastened to it. The role of spar bands against bending in the work of such wings is not great, as a result of which the area of their cross section differs little from the cross sections of separately taken stringers.

Differing from spar-type constructions, the skin of monoblock constructions is relatively thick. The well-fastened skin works fully both under bending and under torsion.

Wing designs of modern flying machines, as a rule, have a skin which fully works under bending and under torsion.

The basic strength elements which absorb bending of the wing are panels which consist of the skin, stringers and spar bands.

The front and rear portions of the profile are closely located to the neutral axis and affect the amount of inertial moment of the section very little. The presence of ailerons and mechanization practically excludes the trailing edge of the wing from working under bending.

Installation of stringers in the leading edge of the wing distorts its profile, while at the same time the requirement for the surface of the wing in this part of the profile is very high. For this reason, stringers are not installed in the leading edge of the wing in a number of cases. In this case, ribs are installed in the leading edge more often to provide the required rigidity against the effect of air loads.

With a relatively thin skin, the ribs are connected not only with the skin but also with the stringers. An example of design execution of this connection is presented in Fig. 49a.

In constructions with a thicker skin, stringer connection with the ribs is not mandatory. It is sufficiently reliably accomplished with the skin itself, as is shown in Fig. 49 b.

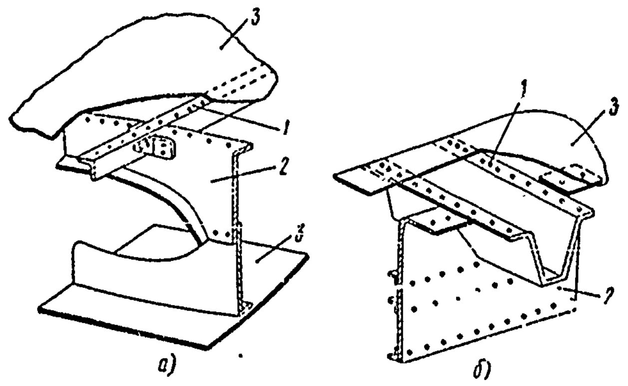

Fig. 49 Connection Point of Skin, Stringer and Rib:

Key: a) connection with thin skin, b) connection with thick skin, 1) stringer, 2) rib, 3) skin

For wings with stringer fastening, so-called panel assembly has received widespread usage. The essence of this consists of the fact that the wing is disjointed into a number of technological panels (Fig. 50) which are then assembled together in a definite sequence. With this, each technological panel is manufactured independently from the others in a special jig in the following order: stringers 1, halves of ribs 2, and spars 3 are connected to the skin which has the necessary shape. The deficiency in panel construction is the increased number of parts and some increase in design weight. However, the number of existing advantages in many cases makes panel assembly preferable to others.

These advantages include:

1) Good wing surface and its accurate correspondence to the outlines of the given profile, since the body is oriented according to the skin during assembly;

2) The entire process of wing manufacture is eased;

-- Assembly of the various wires is simpler;

-- Wide usage of open machine riveting and other processes becomes possible.

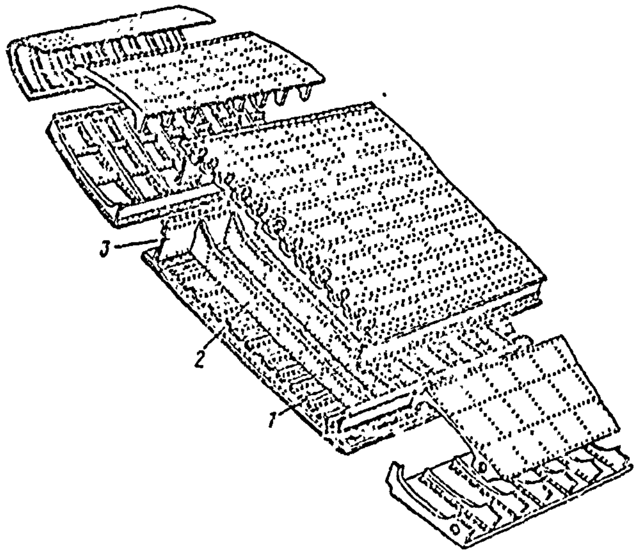

Fig. 50 Technological Wing Panels:

Key: 1) stringers, 2) lower rib half, 3) lower spar half

To satisfy operational and engineering requirements, wings are made detachable and with cuts in the skin. The detachments serve to disconnect the wings from the fuselage due to the necessity for transporting the helicopter, storing it in a storage yard, assembly apparatuses and wires, repair and others. A wing of low weight has, as a rule, two disconnecting points along which it is linked into a center section and two spans. Detachable wings, regardless of the method of connecting their parts, are heavie than non-detachable ones due to the additional weight of the abutting components.

Detachment point designs depend on the strength schematic of the wing and are distinguished by their wide variety. They can, however, be principally broken down into two types:

1) Contour detachments, in which all strength elements of the wing are connected together;

2) Point detachments, in which only certain strength elements of the wing are connected together.

The first type of detachments is most characteristic for wings having a comparatively thick, well-fastened skin.

In the contour connection, a force connection between the skin, spars, stringers and other fastened construct on elements is totally accomplished at the detachment point. Due to this, the force elements at the detachment point and near it participate in bending and torsion of the wing.

The design of a contour detachment is reminiscent of a flanged connection and is usually formed with abutting profiles (Fig. 51a), fittings (see Fig. 51b), angle profiles and others. A contour detachment design in which the force connection of the skin and stringers is accomplished with abutting profiles drawn together with bolts which are located in special shoes has received the most widespread usage (see section A-A, Fig. 51a). The faces of the butting profiles are machined so that they fit tightly together and the bending moment in the compression zone of the wing is transmitted evenly to the support of the butting profiles or fittings.

The deficiency in contour detachments -- the difficulty in assembly and disassembly -- is to a significant degree eliminated in the transfer to point detachments. In point detachments, the force connection between the parts of the wing, is accomplished through components butting only against the spars. The skin and stringers are not immediately connected together and therefore absorb bending moments only at some distance from the detachment point. As the result of this, designs with this type of detachment are heavier by comparison with contoured ones (while providing the same rigidity).

The minimum number of abutting components is three. The possible design of a detachment with three-point fastening is shown in Fig. 52, a. The bending moment in this case is absorbed by bolts which connect the corresponding bands of the main spar. The lower eyes are usually made more massive, since they work under tension. The butting component on the front spar is usually a hinged connection and can provide absorption of the bending moment in a horizontal plane and that of a lateral force in a vertical

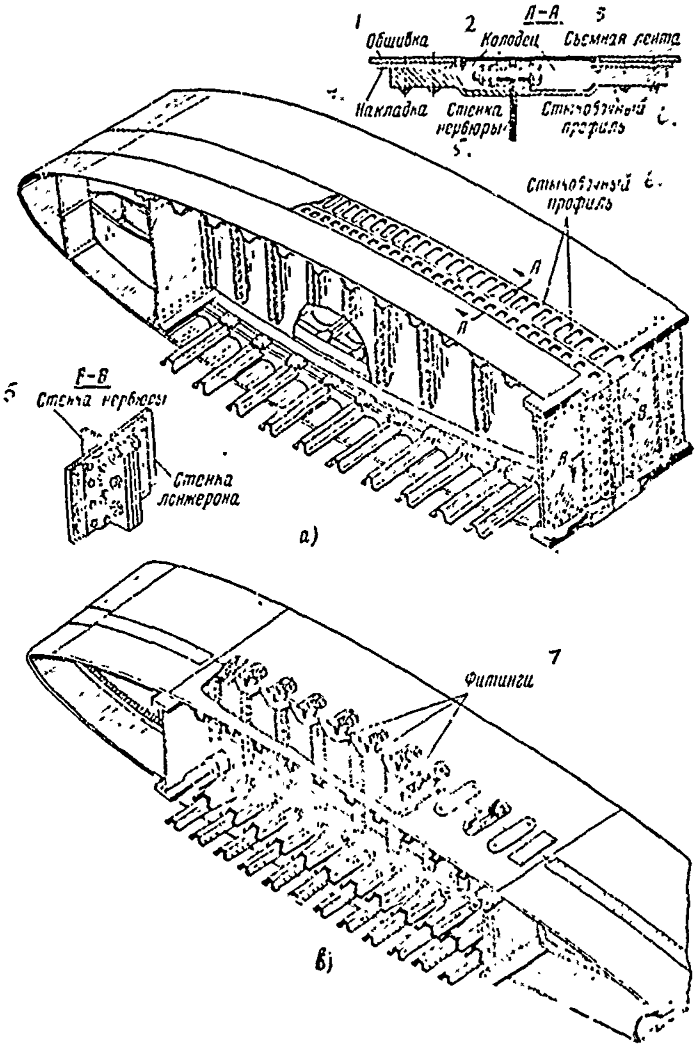

Fig. 51 Contour Wing Detachments:

Key: a) design of a contour wing detachment accomplished with butted profiles; b) design of a contour wing detachment accomplished with fittings.
1) sking, 2) shoe, 3) removable band, 4) liner, 5) rib wall, 6) butting profile, 7) fittings

one. With this construction of the component (The hinge), the front spar does not absorb bending in the vertical plane at the detachment point. According to its distance from the detachment point, due to shear in the skin, it gradually absorbs the bending moment at some distance from

the detachment point (see Fig. 52d).

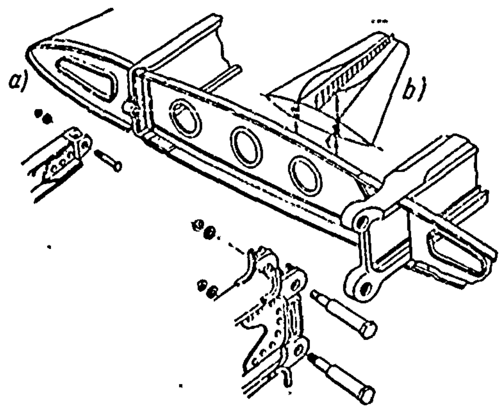

Fig. 52 Design of a Three-Point Detachment:

Key: a) detachment construction, b) diagram of bending moments in a vertical plane absorbed by the spar bands

Various cuts are made in the wings for access to equipment components, for assembly and disassembly of fuel tanks and for other purposes. These cuts destroy the continuity of load-bearing elements of the wing and therefore affect its work. The degree of this influence depends on the size of the cut, the type of load-bearing action, the design formulation of the opening and other factors. Small openings with a small amount of aerodynamic balancing cause practically no deformation of stressed condition in the construction. Balancing of small openings is achieved by means of their framing with corresponding forms and inserts, forming a flat frame. These openings are covered with easily removable covers, whose design is executed sufficiently rigidly so as to maintain form and tightness of fit.

Two types of large openings are encountered:

1) balanced;

2) unbalanced.

Full balancing of large openings is accomplished by means of installing removable load-bearing panels which are equally as strong as the cut-out sections of the wing. Installation of the removable panels on the wing renews the disturbed load-bearing connections and the full transmission of bending and torsion is provided. The removable panels make the wing construction heavier and their assembly and disassembly is more labor-consuming.

If the wing skin is relatively thin and weakly fastened, construction of the removable panels is simplified. In this case, they are fastened only with screws along the contour, providing transmittal of only tangential forces. The rigidity to bending removed because of the opening is renewed by reinforcing the bands of the spars correspondingly.

Large unbalanced openings in the wing must be made for extending the landing gear and in places to which frequent access is required. They weaken the construction essentially, so that significant portions of the skin with the fastened elements near the edges of the opening weakly participate in bending. Therefore, the balancing of such openings is associated with fundamental changes in the load-bearing schematic of the wing (installation of additional ribs and others). Panels covering unbalanced openings are not made to be load-bearing; however, they must possess sufficient strength and rigidity so as to absorb an air load.

The configuration of a helicopter (placement of the wing on the fuselage in height, purpose of the fuselage and other factors) operational and engineering requirements determine the variety of design forms of the root portion of the wing.

The most widely used design is that in which the longitudinal elements working on bending (spars, stringers and the skin), are continued in places occupied by the fuselage (Fig. 53a) and designs in which all the longitudinal elements with the exception of the spars terminate at the side of the fuselage (see Fig. 53b).

Designs of the first type are mose perfect since the skin with the elements next to the fuselage which are fastened to it works under flexion.

The presence of load-bearing elements of the wing inside the fuselage creates great difficulties in accomplishing a desirable configuration in the cargo-passenger cabin.

The basic deficiency in the design of this type consists of the fact that the stringers and skin of the fuselage do not participate in absorbing the flexion moment. Normal stresses in the skin and longitudinal elements fastened to it are practically absent along the section of th inboard rib due to the low rigidity of the rib in the direction perpendicular to its plane. Normal stresses increase as distance from the fuselage increases. At a distance approximately equal to the spacing between the spars, the skin and stringers participate in absorbing the flexion moment of the wing.

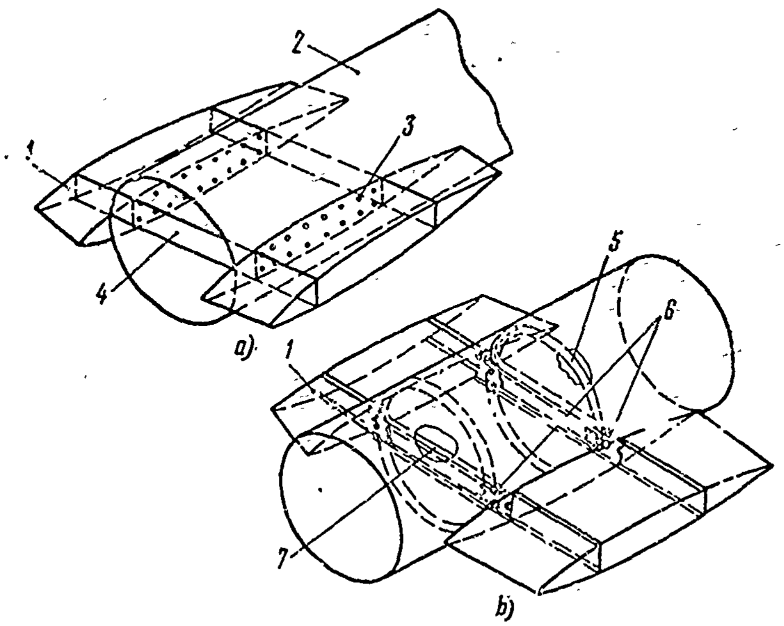

Fig. 53 Wing Center Section:

Key: a) wing center section has a skin inside the fuselage, b) wing center section does not have a skin inside the fuselage, 1) removable portion of wing, 2) fuselage, 3) contour butt, 4) center section, 5) frame, 6) connecting fittings, 7) spar

Fig. 54 shows the wing of a helicopter. It consists of three parts: the right and left spans 6, symmetrically arranged relative to the fuselage and the center section beam 1.

The wing has two basic detaching points, along which both spans are butted against the center section beam with a flanged connection.

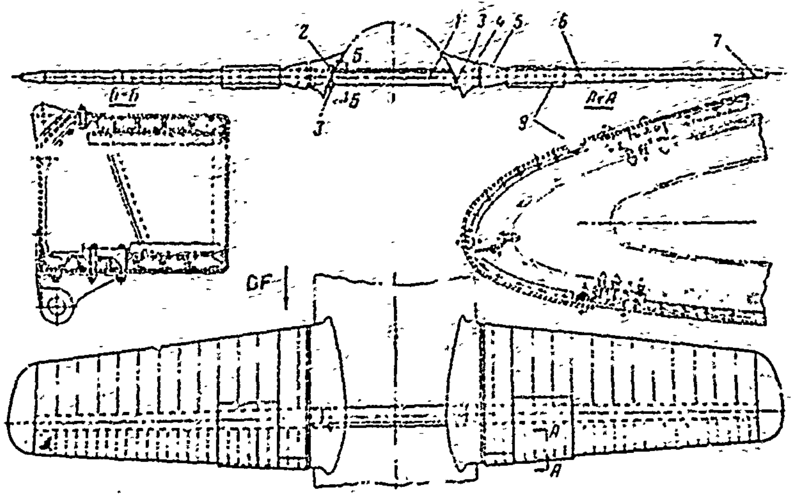

Fig. 54 Wing of a Single-Rotor Helicopter:

Key: 1) center section beam, 2) wing control mechanism, fastening fitting, 3) wing suspension fitting, 4) fillet on fuselage (stationary), 5) fillet on wing (movable), 6) wing span, 7) tip fairing, 8) shield

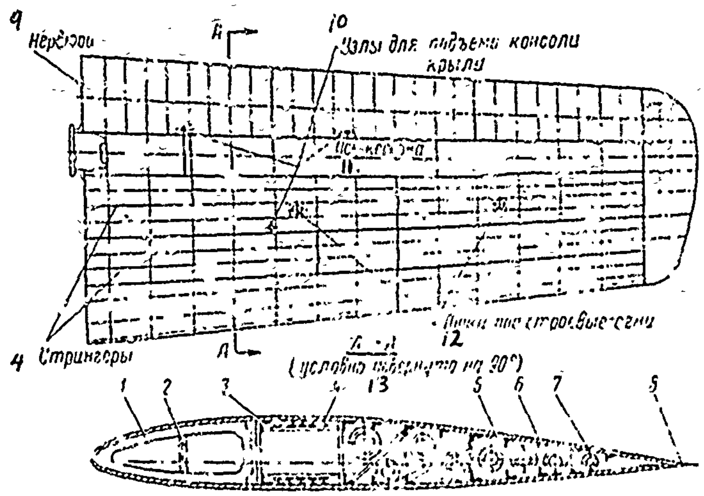

Fig. 55 Wing Span of Single-Rotor Helicopter:
Key: 1) rib leading section, 2) angle fitting, 3) inner skin, 4) stringer, 5) rib trailing section, 6) stringer 7) outer skin, 8) trailing edge stringer, 9) rib, 10) fittings for lifting wing span, 11) torsion box axis, 12) ports for position lights, 13) (arbitrarily turned by 90°)

The span (Fig. 55) is a riveted construction and consists of a center, leading and trailing portions, and a tip. The center portion of the span is a box-shaped type of riveted construction and consists of a longitudinal set of stringers 4, fastened with diaphragms.

The leading and trailing portions of the wing consist of a set of ribs and stringers and have a skin made out of duralumin sheet.

The section of the wing which is subjected to the most heat from exhaust gases is protected with a special shield 8 (see Fig. 54), which is installed on angle fittings made of a material with low heat conductivity. There is a clearance between the shield and the wing skin for passage of cold air.

On the surface of the span are ports for the installation of position lights,and fittings 3 for lifting the wing during its assembly and disassembly are also built in.

The center section beam 1 is a riveted construction which is rectangular in section (Fig. 56).

On the bottom of the beam near the front wall are two fittings 2 for attaching the wing to the fuselage and a fitting on top for fastening the hydraulic mechanism for control of the wing. The wing is fixed in two positions. In all configurations of motor flight, the wing is fixed in a single position, and with a transfer to autorotation of the main rotor, the angle of wing setting is changed by the hydraulic mechanism, and the wing is fixed at another, lighter, angle.

In view of the fact that the induction stream of air from the rotor is assymetrical, the right and left spans have different angles of setting.

Fig. 56 Suspension of Wing on Fuselage (Fillet Removed): Key: 1) center section beam, 2) hinged wing suspension fitting, 3) flanged butt joint of wing with center section beam

There are fillets on the wing to provide a smooth joint between the wing and fuselage (to cover the center section beam and the hole in the fuselage skin). The fillet consists of two separate parts: one of its parts is fastened stationary to the fuselage, and the other, a movable one, is fastened on the wing and deflects together with it.

High-Lift Devices

The term high-lift devices indicates structures which provide an increased carrying capacity of the wing at low airspeeds of the helicopter. High-lift devices may be based on the following principles:

a) an increase in airfoil camber;

b) an increase in wing area;

c) control of the boundary layer for the purpose of delaying the appearance of stall;

d) control of circulation.

Fig. 57 presents diagrams of the basic types of high-lift devices. The split flap spoiler, when deflected, increases the camber of the initial airfoil. Besides this, suction of the boundary layer away from the upper surface of the wing occurs in the vacuum zone between the wing and the spoiler. The split flap spoiler has a low weight, is simple design-wise and is convenient and reliable in operation.

The extensible flap spoiler gives a great increase to the lift force by comparison with the simple one, since it moves backward at the same time it is deflected, increasing the area of the wing. Extensible spoilers are more complex design-wise and have a greater weight by comparison with simple ones.

The flap is a trailing portion of the wing, which is deflected downward. Simple and slotted flaps are different. The slotted flap is distinguished from the simple bone by the presence of a shaped slot between the flap and the main part of the wing when the flap is in the deflected position. When the slotted flap is deflected, the effect of blowing off the boundary layer on the upper surface of the flap is added to the effect of the increased camber.

Therefore, the slotted flap provides a greater increase in lift force than does the simple one.

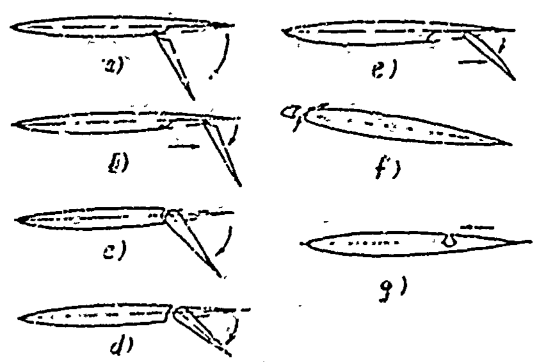

Fig. 57 Basic Types of High-Lift Mechanisms:

Key: a) split flap spoiler, b) extensible flap spoiler, c) simple flap, d) slotted flap, e) extensible split flap, f) leading edge slat, g) boundary layer suction

An airfoil-shaped extensible panel is called an extensible split flap. The extensible split flap provides a significant increase in the lifting capacity of the wing due to the presence of the slotted effect, increasing the area of the wing and the camber of the airfoil. Regardless of this, however, extensible split flaps have not been widely used due to their high weight and design difficulties connected with locating the extensible split flap and the mechanism for its control.

The leading edge slat is an airfoil-shaped leading edge of a wing which is moved forward at high angles of attack either by force or automatically due to the effect of aerodynamic forces. The increase in the lift force takes place due to the blowing-off of the boundary layer from the upper surface of the wing by a stream of air which passes through the shaped slot between the leading edge slat and the wing, and also due to the increase in the wing area. Leading edge slats located opposite the aileron increase lateral stability and controlability at high angles of attack.

Control of the boundary layer (suction or blowing) delays stalling, increases the lift force and decreases the drag of the wing. The slot through which suction of the boundary layer occurs is located at the point of possible stall.

From the point of view of design formulation, high-lift devices can be divided into two types. The first type includes elements having the closed contour of the skin (leading edge slats, flaps and extensible split flaps). They are beams which absorb lateral force and flexion and torsion moments. The lateral force is absorbed by the walls of the spars, the flexion moment is absorbed by the bands of the spars and partially by the skin, and the torsion moment is absorbed by the closed contour of the skin (Fig. 58a). The second type includes high-lift device elements (lift flap spoilers) which do not have the closed contour of the skin and therefore are not capable of absorbing the torsion moment (see Fig. 58b). The spoiler is a plate which is fastened in one direction by the ribs and in the other direction by the spar and rear stringer. The spoiler is fastened to the wing with a continuous hinge, around which it rotates while opening. Control of the spoiler is provided by a rod which moves along the span of the wing. The rod is connected to the spar of the spoiler with adjustable coupling rods.

The air load is transmitted from the skin of the flap to the ribs which work, like beams, resting on the spars and continuous hinge connections. Since the ribs are riveted to the skin, the latter participates in absorbing the flexion moment together with the ribs. The air load , transmitted to the spar, forces it to work on flexion like the beam resting on the coupling rods.

Empennage and Aileron Design

The tail empennage is intended to provide longitudinal and directional balancing, stability and controlability.

The term balancing of a helicopter means of the moments of all forces relative to its center of gravity, the term stability means the capacity of the helicopter to return to its initial configuration of flight after the forces causing its deviation cease to act, and the term controlability means the capability of changing the flight configuration of the helicopter according to the will of the pilot or with the control installation.

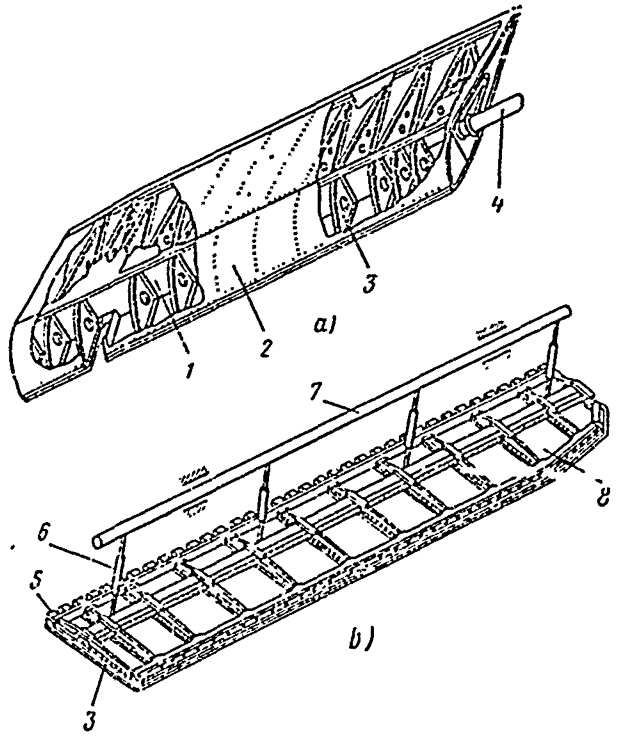

Fig. 58 High-Lift Device Design:

Key: a) flap, b) spoiler, 1) spar, 2) skin, 3) rib, 4) rib, 5) pipe rigidly connecting both halves of flap, 6) coupling rod, 7) main rod, 8) lower skin

The tail empennage usually consists of a horizontal and vertical plane. The plane may in turn be divided into movable and stationary portions. Stationary portions include the horizontal and vertical stabilizers and movable portions include the elevator and rudder.

The design of the stationary portions of the tail empennage is similar to the design of a wing.

The elevator is attached to the horizontal stabilizer and the rudder is attached to the vertical stabilizer. There are usually more than two attachment fittings. Attachment of the elevator (Fig. 59) is accomplished with one stationary support (part I) and two or more hinged (movable) supports (part II).

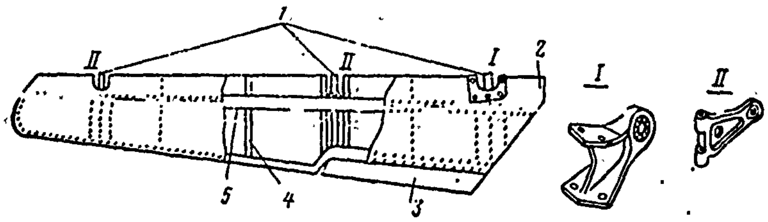

Fig. 59 Elevator Design:

Key: 1) suspension fittings, 2) skin, 3) trim tab, 4) rib, 5) spar, I) stationary support, II) movable support

Axial forces along the elevator are absorbed only by the stationary support.

The spar is a bent trough-shaped form made of aluminum alloy. At points of high flexion moments (in the suspension fittings), the spar is reinforced with additional inserts. The skin serves to form the airfoil of the elevator and to absorb the torsion moment.

In places where the fastening fittings of the elevator are located, the contour of the airfoil does not have a skin and the torsion moment is abosrbed only by the rear contour. To transmit the torsion moment from the front contour to the rear one and vice versa, ribs are inserted along the edges of the openings for the fastening fittings of the elevator. Balancing loads are usually provided in elevator s and serve to prevent self-incited oscillations of the part. For the purpose of best using the skin to absorb the flexion moment and maintain the form the airfoil, it is reinforced with honeycomb filler. To provide stability and controlability of the helicopter, a stabilizing fin, either controllable in flight or stationary (with the elevator) is installed on it. The angle of attack of a controllable stabilizer fin is changed with the "pitch -- gas" lever, simultaneously with changing the main rotor collective pitch setting or when the longitudinal direction lever is deflected. The stabilizing fin angle of attack can be set on the ground.

The design of a controllable stabilizer fin (Fig. 60) differs little from the design of a stationary one. The major difference is determined by the fact that the fastening of a controllable stabilizer fin to the tail beam must provide free rotation of the stabilizing fin through some range of angles.

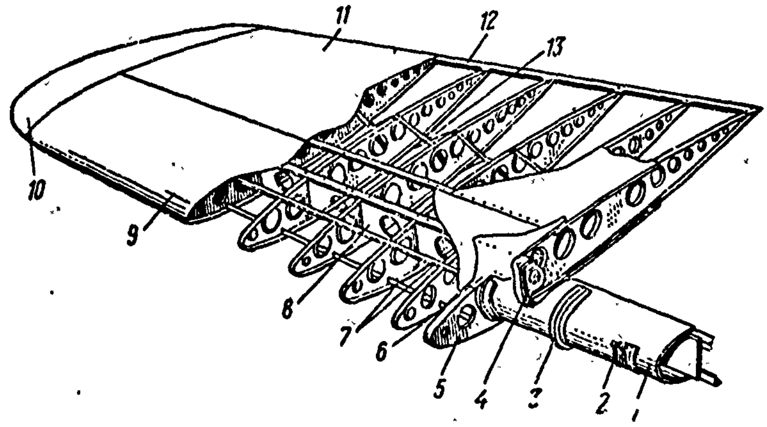

Fig. 60 Span of a Controllable Stabilizer Fin:

Key: 1) middle portion of spar, 2) control rod fastening fitting, 3) flanged spar connection, 4) stabilizer fin fastening fitting, 5) rib, 6) insert, 7) stringers, 8) spar, 9) duralumin skin, 10) tip, 11) fabric skin, 12) trailing edge stringer, 13) band

The stabilizer fin consists of a right and left half which are symmetrically located relative to the tail beam and connected together by their spar. The design of a stabilizer fin is similar to that of a wing. A stabilizer fin consists of a spar 8 (see Fig. 60), a set of ribs, a nose portion duralumin skin 9, tail portion linen skin 11, tip 10 and stabilizer fin hinged fastening fitting 4. The spar is of the beam type and is of riveted construction. The upper and lower bands of the spar are made of duralumin angles which are connected by a stamped diaphragm. The right and left halves of the stabilizer fin are butted onto the spar with a flanged connection. The suspension fittings of the stabilizer fin are installed on the spar at its butt rib. The fastening fitting of the stabilizer fin control

rod is installed on the spar.

A flexion moment, acting the stabilizer fin, is absorbed by the spar for all practical purposes and a torsion moment is absorbed by the closed contour of the ~kin and is then transmitted through the reinforced rib to the spar.

Ailerons, deflecting upward and downward, provide lateral controllability of the apparatus. The moments arising during deflection of the ailerons due to the ~reation of an additonal lift force on the wing, roll the flying apparatus.

With identical deviation of the ailerons, a yaw moment arises due to a difference in the resistance of the right and left spans of the wing. Control of the ailersons is usually effected differentially (the lowered aileron is deflected at an angle smaller than that of the raised one). This equalizes the resistance in the spans of the wing and decreases the moment of yaw while rolling.

In a design sense, there is no principal difference between an aileron and an elevator. Just as in the elevator, a lateral force is absorbed by the wall of the aileron spar, the flexion moment is absorbed by the bands of the spar and partially by the skin, and the torsion moment is absorbed by the closed contour of the skin (Fig. 61).

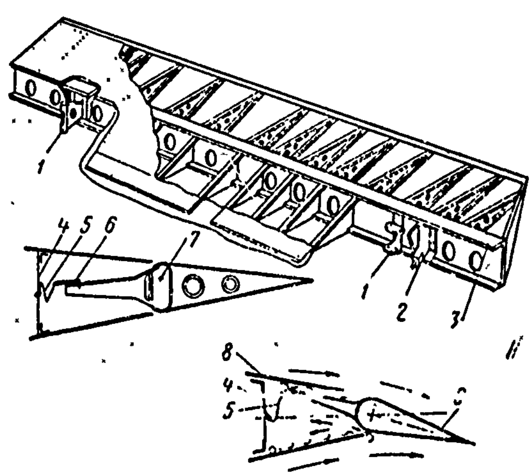

Fig. 61 Design of an Aileron with Internal Aerodynamic Balancing:
Key: 1) suspension fittings, 2) control arm, 3) spar, 4) rear wall of spar, 5) internal balancing sealing fabric, 6) counterweight, 7) axis of aileron rotation, 8) ~kin, 9) aileron. A diagram of internal aerodynamic balancing is shown below.

Internal aerodynamic balancing is used on the aileron. The leading edge of the aileron is connected to the rear wall of the wing by rubberized fabric which hermetically separates the upper and lower areas of the rearward surfaces of the wing. Due to the difference in pressure on the leading edge of the aileron, a moment is created relative to its axis of rotation which is opposite the moment from its trailing portion. As a result, the hinge moment from the aileron is decreased. The counterweight in the form of a steel plate is usually fastened to the leading edge of the aileron to prevent vibration.

Section 4

Tail (Steering) Rotors

Purpose of Tail Rotors and Requirements Stipulated for Them

A tail rotor whose pitch is changeable in flight is intended for equalization of the reaction moment of the main rotor and for directional control of a single-rotor helicopter having a mechanically driven main rotor.

Rotation of the rotor is effected from the main reduction gear through a transmission, intermediate and tail reduction gears. The tail rotor is installed on the output shaft of the tail reduction gear which is mounted on the tail boom. The pitch of the tail rotor is controlled by pedals from the pilot's cockpit. A change in the pitch will lead to a change in thrust and will provide a turn of the helicopter to one side or the other. During straight flight, the direction of thrust is perpendicular to the direction of flight. During the horizontal flight configuration, the blades of the tail rotor work in an asymmetrical stream like the blades of the main rotor.

To decrease the moment acting on the shaft of the tail reduction gear and decrease the changing stresses on the root portion of the blades, horizontal hinges are used in the hub of the tail rotor.

When the pitch is changed, the blade rotates in an axial hinge. Rotation is accomplished by progressive movement of the pitch changing linkage which is connected to the blade turning arms on the axial hinge bodies by means of rods.

Tail Rotor Blade Design

The blades of a tail rotor are similar to the blades of the main rotor in design.

The blade of a tail rotor (Fig. 62) is a one-piece metal construction with a fiberglass skin. The basic load-bearing element of the blade is the spar 4 which is manufactured of a pressed profile and machined to the required contour. The tail portion which consists of honeycomb block 5 and fiberglass skin 6 is bonded onto the rear wall of the spar. The honeycomb block is bonded out of aluminum foil

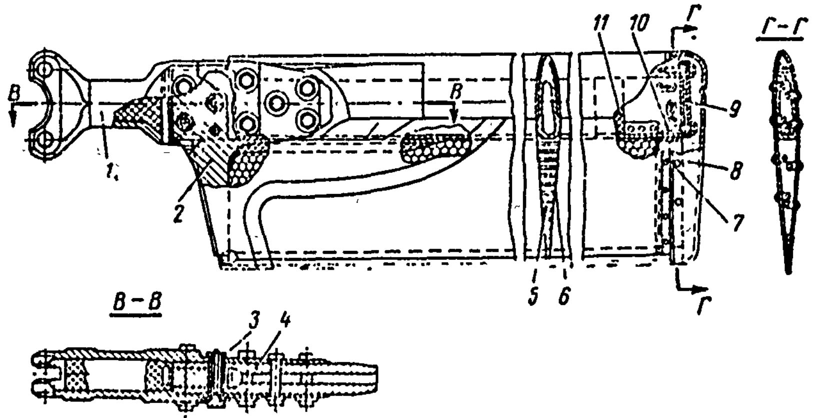

Fig. 62 Tail Rotor Blade:

Key: 1) steel connector, 2) bracket, 3) bolt, 4) spar, 5) honeycomb block, 6) skin, 7) tip end rib, 8) tip fairing, 9) balancing load plates, 10) pin, 11) plug

A steel connector 1 to which bracket 2 is fastened with bolts 3 is fastened onto the root portion of the spar. A plastic foam insert is installed inside the connector. At the tip part of the spar there is a plastic foam plug 11 and threaded-in pins 10 on which are fastened balancing load plates 9. The tip end rib 7 to which the tip fairing 8 is fastened with screws is installed on the rear portion of the blade.

The electric heating elements 5 (Fig. 63) which are bonded between the layers of fiberglass, are installed on the leading edges of the tail rotor blades. Rubber 2 and plate 1 of stainless steel are bonded on the leading edges of the blades to protect them from abrasive action.

The heater is located along the entire length of the blade. A current pickup serves to transmit current from the on-board circuit to the heating elements of the blades.

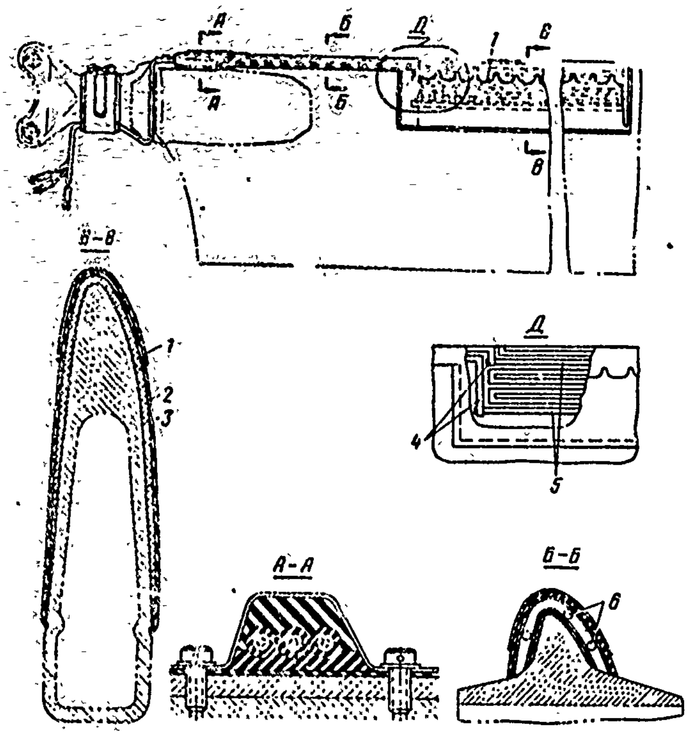

Fig. 63 Anti-Icing Installation of a Tail Rotor Blade:

Key: 1) metal plate, 2) layer of rubber, 3) insulated packet with heating elements, 4) connecting buses, 5) heating elements, 6) wire

Tail Rotor Hub Design

A tail rotor hub (Fig. 64) consists of the following basic parts: the body, brackets, cups and linkage.

Hub body 7 has eyes, in each of which pin 10 of the horizontal hinge which fastens bracket 11 is installed on needle bearings. Due to the horizontal hinges, the thrust force passes through the center of the hub and does not load the root portion of the blade with a flexion moment.

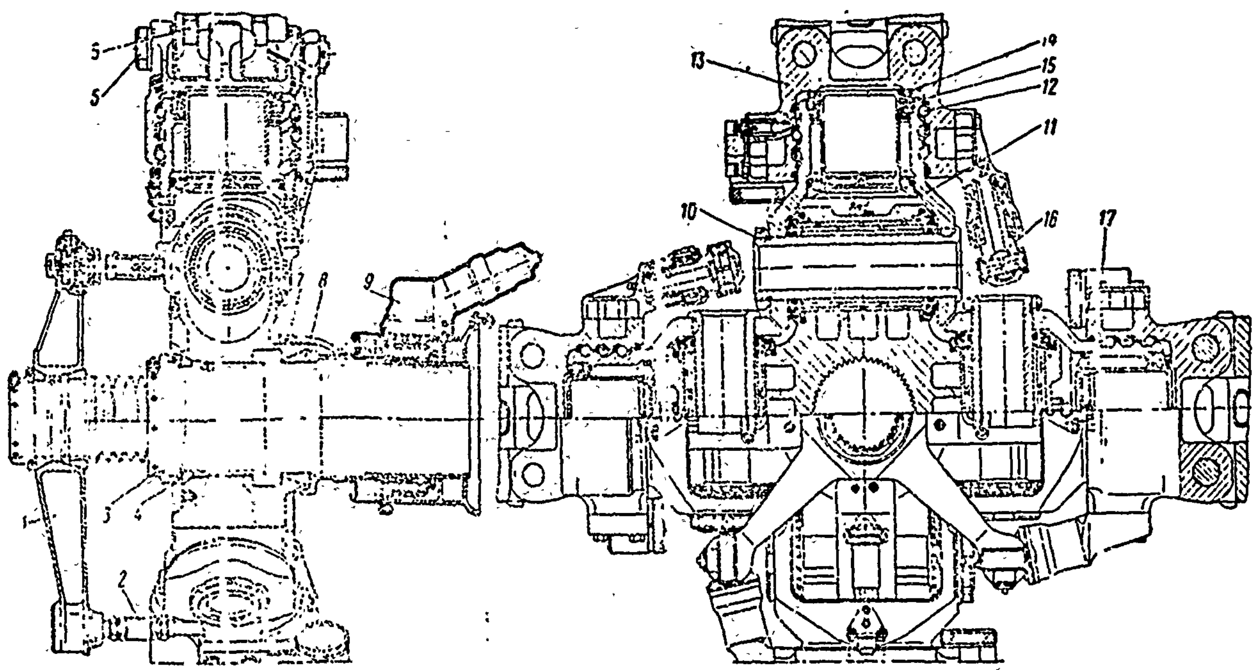

Fig. 64 Tail Rotor Hub:

Key: 1) pitch changing linkage cross, 2) rod, 3) nut, 4) front cone, 5) track bolts, 6) blade connector, 7) hub body, 8) rear cone, 9) tail rotor current pickup, 10) horizontal hinge pin, 11) bracket, 12) axial hinge bearing ball, 13) axial hinge cup, 14) roller bearing, 15) nut, 16) blade turning arm, 17) counterweight

The hub body is connected to the shaft of the tail reduction gear with involute splines. The body is centered with cones 4 and 8. The hub is fastened by nut 3.

Centrifugal force and the flexion moment are transmitted from the blades to the hub from cup 13 of the axial hinge through the three rows of ball bearings 12. The balls are encased in a retainer, the outer race is the cup and the inner race of the axial hinge bearing is the bracket.

To eliminate shock loads on the axial hinge bearing balls, a preliminary tension of all three rows of bearings is created with nut 15, which is in contact with support roller bearing 14. The cup on the butt side has eyes for fastening the blades and on its cylindrical surface it has two diametrically opposed surfaces for fastening counterweights 17 and blade turning arm 16. The counterweights, whose centrifugal forces create a moment relative to the longitudinal axis of the blade, are installed at the root for relieving them of large stresses in the steering direction. Counterweights are selected in such a manner that if the rotor blade control system fails, they can independently be set at an angle corresponding to cruise flight configuration. The blade turning arm is intended to covert the progressive movement of linkage cross 1 into a rotational movement of the axial hinge cup.

The cross is connected with the turning arm by adjustable rod 2. The angle of blade setting is adjusted by changing the length of this rod. The blade turning rod is connected to the linkage cross with a spherical bearing and it is connected to the blade turning lever with a universal hinge (type of universal joint).

The pitch changing linkage cross is installed on a slide of the reduction gear on splines and centering cones similar to the installation of the hub body. Hinged connections of the blade turning arms are mounted on the ends of the cross arms.

Section 5

Helicopter Power Plant

Requirements Stipulated for Power Plant

The main rotor and its control are independent parts of the design and are not included in the power plant of a helicopter.

The power plant of a helicopter consists of the following parts:

1) The engine with its accessories and ignition, starting and control systems;

2) Mounting of the engine to the helicopter frame;

3) Engine cowlings, fairings and nacelles;

4) Engine fuel and lubricant provision systems;

5) Engine and engine accessory cooling system;

6) Air cleaners and exhaust pipes;]

7) Systems for control and monitering operation of power plant accessories;

8) Fire extinguishing installation.

Turboprop engines with a free turbine are generally installed on modern helicopters with mechanically driven main rotors. The basic requirements stipulated for the power plant of a helicopter are the following:

a) High work and reliability of all elements of the power plant;

b) Strength of the load-bearing elements in all cases of loading stipulated in the Norms of Strength;

c) Elastic fastening of the engine and accessories to provide dampening of vibration in the power installation itself;

d) Simplicity and convenience in assembly and disassembly of the engine and accessories;

e) Good access to the engine and its accessories for their inspection and performance of adjustments in the process of operation.

Placement of Power Plants

The placement of power plants is determined by operational considerations, requirements for weight centering and layout. Power plants are located inside the fuselage (in the middle or nose parts) and outside it, when the engines are located in separate nacelles or above the fuselage (see Figs. 10 and 13).

Location of the power plant provides for wise placement of all accessories, systems and installations providing the normal operation of the power plant as a whole.

Forced blowing of air past the cylinder heads by a special fan is provided in helicopters with piston engines during the hovering and vertical takeoff configurations, since in these configurations natural passage of air past them due to velocity pressure created during the progressive motion of the helicopter is absent.

Mounting of Engines

Turboprop engines are mounted to the frame of a helicopter with two bands (Fig. 65). The front mounting band (section A-A) is located on the compressor body. The front suspension provides the possibility for the engine to move forward relative to its rear support during its thermal expansion.

For this purpose, the engine fastening mounts have hinged self-setting supports at the mounting points on the front band and on the fuselage brackets.

With this fastening of the engine, axial forces are absorbed only by the rear support (section B-B). The torsion moment is absorbed by the front and rear supports. Forces of inertia are absorbed by the front and rear supports proportional to the distance from the center of gravity of the engine.

The forward fastening consists of three identically constructed adjustable mounts with rubber shock absorbers (Fig. 66 a), which eliminate the transmittal of engine osciallations to the fuselage.

The possibility of adjusting the installation of the engine in the vertical plane is provided by means of changing the length of the rods. Fastening of the engine along the rear band is accomplished in the form of a support which consists of two brackets (see Fig. 66b). Bushings 7, in which the engine pins are fastened by nuts 2, are installed in the brackets on shock absorbing rings 5. Engine installation in the horizontal plane can be adjusted with these nuts. Special inserts under the brackets are provided for adjusting engine installation in height.

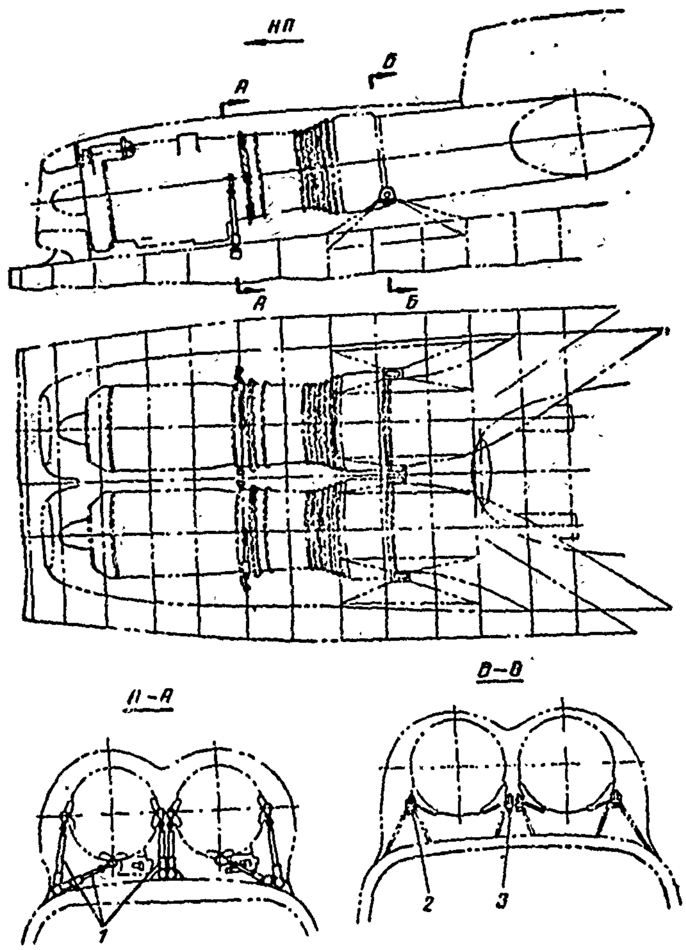

Fig. 65 Diagram of Fastening Engines on a Helicopter:

Key: 1) adjustable mounts, 2) bracket for fastening engine on outer side, 3) bracket for fastening engine on inner side.

The second support of the rear mount has a "floating" ring, which is not fixed relative to the bracket body (see Fig. 66c). Due to this support design, additional axial loads in the support during thermal expansion of the engine in the area of the rear fastening band are not created.

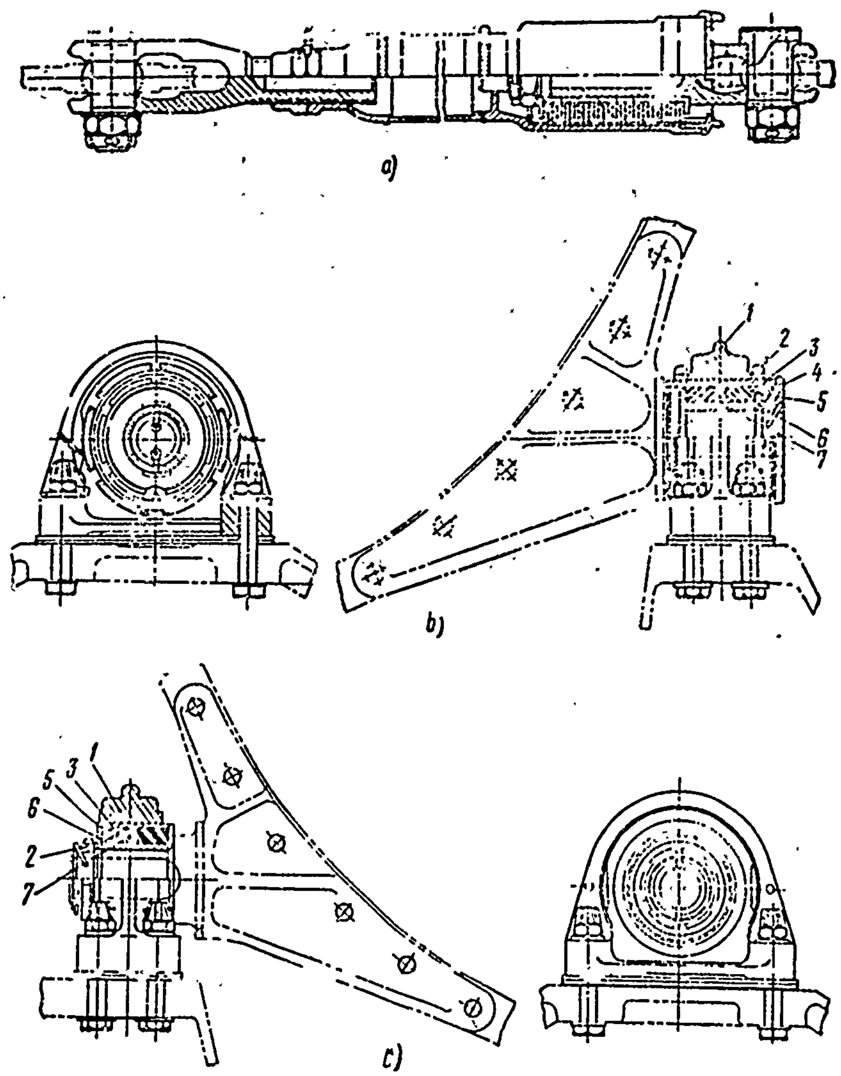

Fig. 66 Fittings for Fastening the Engine:

adjustable engine fastening mount for front band (a). brackets for fastening engine along rear band on outer (b), and inner (c) sides.

Key: 1) body, 2) adjusting nuts, 3) ring, 4) shaped nut, 5) shock absorbing ring, 6) washer, 7) bushing

Shock absorbing rings 5 fulfill the same role as the rubber shock absorbers of the front fastening mounts.

The Fuel System

The fuel system (Fig. 67) includes the fuel tanks, fuel pumps, fuel measuring apparatus, shutoff, fire extinguishing and drain valves, coarse and fine cleaning filters, connecting pipelines, check valves, vent lines, and also lines and components of the neutral gas system.

In the helicopter fuel system reviewed, the main fuel is located in soft tanks. In addition to the soft tanks, installation of metal suspended tanks along the sides of the fuselage is provided.

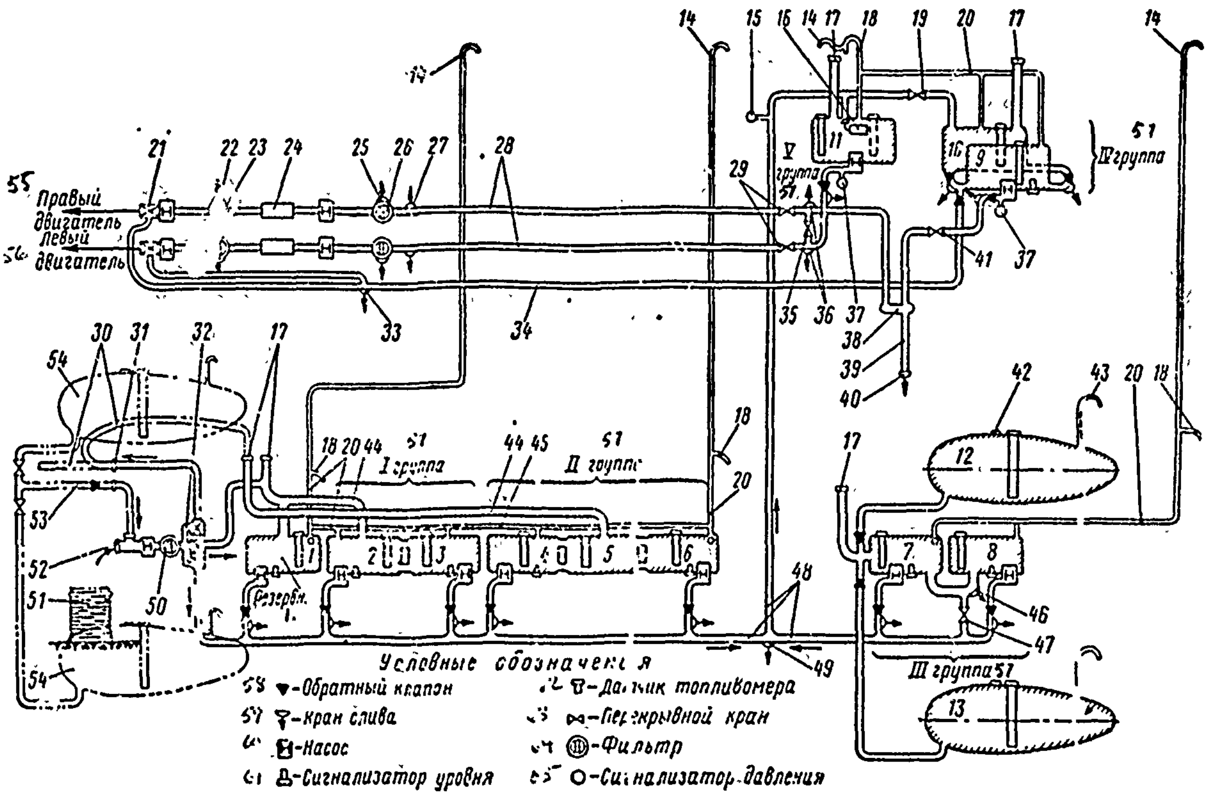

Fig. 67 Principal Diagram of Fuel Feed:

Key: 1) reserve fuel tank; 2, 3, 4, 5, 6, 7 and 8) lower fuel tanks, 9, 10 and 11) upper fuel tanks, 12 and 13) suspended fuel tanks, 14) pipeline for heating vent with warm air, [Key continued on following page.]

[Key to Fig. 67 continued.]

15) pressure sensor; 16) float valve; 17) filler neck, 18) exhaust for venting fuel overboard (into the atmosphere); 19) electromagnetic shutoff valve for onboard refueling; 20) vent line; 21) engine shutoff valve; 22) fine cleaning filter sediment drain valve; 23) fine cleaning filter; 24) fuel flow meter; 25) coarse cleaning filter sediment drain valve; 26) coarse cleaning filter; 27) pipeline sediment drain valve; 28) fuel system lines; 29) fire shutoff valve; 30) repumping hose for filling second group of tanks from helicopter-transportable fuel capacity; 31) fitting for fuel dispatched to consumers; 32) special triple valve; 33) valve for draining fuel from pipeline; 34) line for draining fuel into tank from engine shutoff valves; 35) cut-off valve; 36) air bleed valves; 37) fuel pressure sensor; 38) fuel collector; 39) line for draining fuel from upper tanks; 40) valve for draining fuel from upper tanks; 41) shutoff valve for separate draining of fuel from fourth and fifth groups of tanks; 42) suspended tank filler neck; 43) suspended tank vent line; 44) filler line; 45) vent connection of first and second tank groups; 46) valve for draining sediment from connecting lines and for draining fuel from tanks of group III; 47) shutoff valve for refueling Group III tanks; 48) repumping line; 49) fuel drain valve for lower tanks; 50) coarse cleaning filter; 51) airport storage; 52) intake fitting for pumping fuel from airport storage; 53) fitting and hose for pumping on the ground and in flight from helicopter-transportable storages; 54) helicopter-transportable storages; 55) right engine; 56) left engine; 57) group; 58) check valve; 59) drain cock; 60) pumps; 61) level signalling mechanism; 62) fuel measuring sensor; 63) shutoff valve; 64) filter; 65) pressure signalling mechanism

To provide the best centering of gravity in a helicopter, the consumption of fuel from the tanks must take place in a definite sequence. Electric transfer pumps which create the necessary pressure before the engine pumps are installed in each group of tanks. Fuel measuring sensors are installed in the tanks.

Check valves are installed on the outlets of each of the transfer pumps and, in case of a fuel leak in one of a group of tanks, prevents fuel from flowing out of the system through the faulty tank.

Fuel from all the tanks is transferred into one consumption tank 11. This tank has a special floating valve 16 which does not allow it to become overfilled during the transfer of fuel.

Consumption from the tanks and the sequence of turning the transfer pumps on and off takes place automatically with a fuel measuring device with consideration for keeping the operational center of gravity of the helicopter within allowable limits.

Fuel from the tanks flows to an electromagnetic fire shutoff valve 29, passes through coarse cleaning 27 and fine cleaning 23 filters and then to the engine pumps. The fuel flows from the pumps through shutdown valves 21 along pipelines to the jets. Fuel flow sensors 24 provide a measurement both of momentary and of total consumption of fuel.

The fuel flow meter gives an indication both of the total reserve of the fuel in the tanks and of that separately in each group of tanks and also separately in tank number 1 and in both suspended tanks.

Fuel tanks may be refilled in three ways: Airport refueling vehicles, on-board refueling from ground storage and helicopter-transported storage.

The tanks are filled with fuel through filler necks 17.

The tanks may be filled with fuel from ground storage (in the absence of a fuel service vehicle) with a special on-board filler. The on-board filler consists of an electric pump and a fuel filter.

The fuel tanks are manufactured of a kerosene-resistant rubber and a protective layer of kapron fabric.

The bottoms of the tanks (Fig. 68) are protected by two layers of sponge and their top parts are protected by one layer of sponge. If the tank is damaged, the rubber, swelling from the kerosene, tightens the puncture, blocking leakage of fuel.

The tanks are placed in special containers. The containers are covered on top with removable panels, under which are located the filling, venting, fire protection and neutral gas systems, fuel lines and also electric wires to the fuel measurement sensors and fire signal mechanism system.

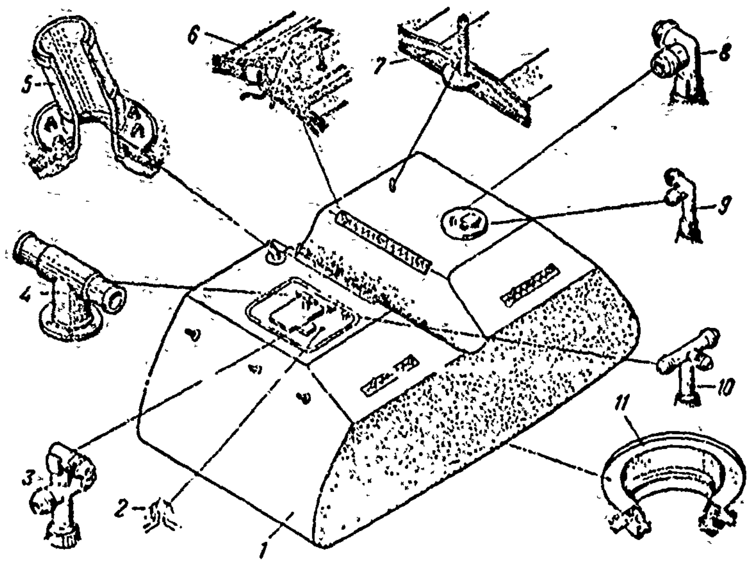

Fig. 68 Soft Fuel Tank Design:

Key: 1) fuel tank, 2) plug, 3) fuel line vent cross, 4) fuel line transfer Tee, 5) filler neck, 6) studs laced to tank, 7) studs vulcanized to tank, 8) fuel line vent Tee, 9) fuel line neutral gas system Tee, 10) fuel line neutral gas system cross, 11) flange for fastening transfer pump (on bottom of tank)

The tank is installed in the container through an opening. The top of the opening is covered with the panels and plate of the tank, by which it is fastened to the container. The additional top wall of the tank is fastened to the top sheet of the container with special studs, part of which are vulcanized in the top wall of the tank 7, and the other part of which are fastened to plates which are laced to special boots which are sewn and bonded to the tanks. To ease assembly of the tanks, holes are provided in the studs for wires, by which the studs are guided into the corresponding holes in the container.

Suspended fuel tanks are fastened along the sides of the fuselage (Fig. 69). The suspended tanks are cylindrical in form and are welded. The construction of the tank consists of a skin, load-bearing and intermediate frames and bulkheads with holes to dampen hydraulic shock of the fuel during the helicopter's maneuvers.

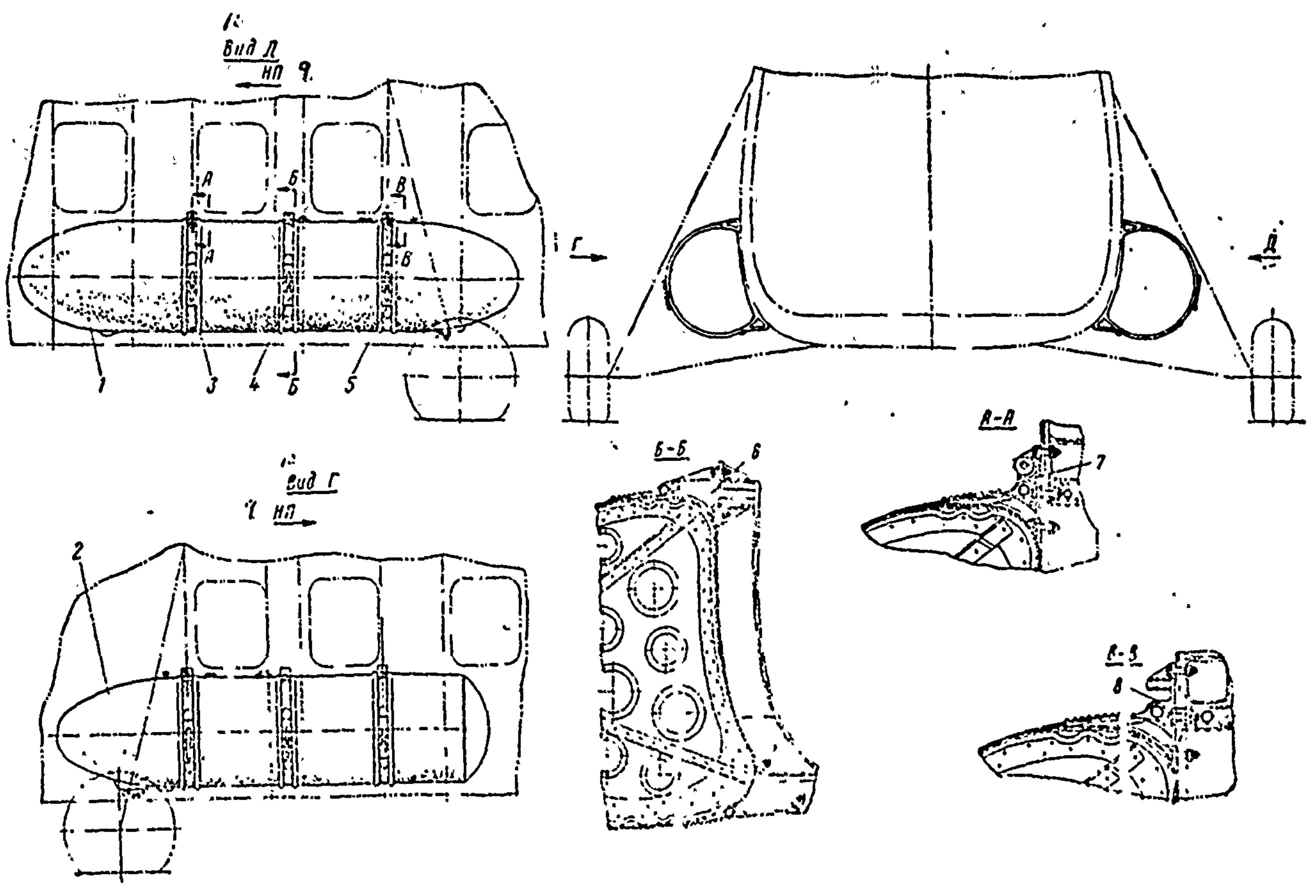

Fig. 69 Installation of Suspended Tanks:

Key: 1) left tank, 2) right tank, 3, 4 and 5) tank fastening bands, 6, 7, and 8) tank fastening brackets, 9) direction of flight, 10) view

The upper par‘ of the tank has a filler neck and a vent fitting and t .e lower part has a fitting for fuel intake. Suspended tanks are fastened to special removable spars which are hung outside the sides of the fuselage with braces.

The neutral gas system (Fig. 70) is intended to prevent the formation of explosive mixtures of fuel vapors and oxygen from the air in the fuel tanks.

Carbon dioxide (CO_2) located in cylinders 10 is used as the neutral gas. The cylinders have a blocking head with a remotely controlled pyrotechnic release 11. Carbon dioxide in a gaseous condition flows along the pipelines into reduction valve 3 and then, at a reduced pressure, into the metering calibrated nozzle and from it into the upper part of the fuel tanks, filling the free volume of the tanks.

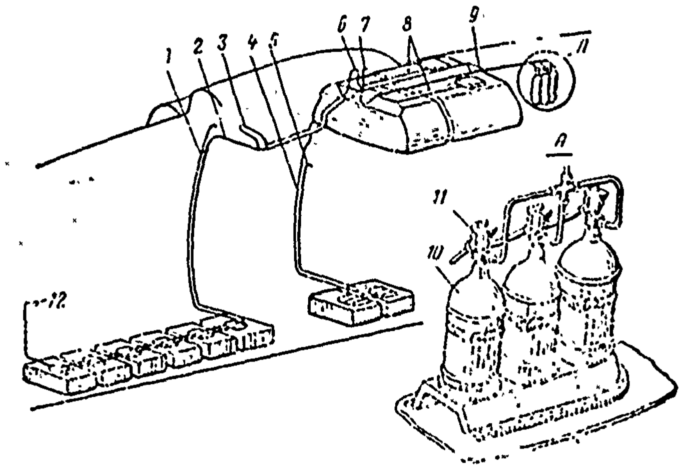

Fig. 70 Neutral Gas Layout:

Key: 1) vent line of group II tanks, 2) neutral gas line to groups I and II tanks and to tank number 1, 3) reduction valve, 4) neutral gas line to group III tanks, 5) group III tanks vent line, 6) neutral gas line to feed tank, 7) vent line of feed tank and group IV tanks, 8) neutral gas line to group IV tanks, 9) neutral gas line from cylinders into system, 10) neutral gas cylinder, 11) neutral gas block with pyrotechnic release, 12) vent line of group I tanks

To prevent the reduction valve with the metering nozzle from freezing, it is installed on a bracket on the frame fastening the main reduction gear in an area of high temperature from the engine exhaust pipe.

The Cooling System

Air flows into the cooling system (Fig. 71) from a fan installation.

The major part of the air is used to cool the oil radiators of the main reduction gear and the engine. The remaining portion of the air flows along tubes to cool: the anti-icing system generator, the starter-generators, air compressor and hydraulic pumps, engine exhaust pipes and is also used for ventilating and heating the helicopter cabin.

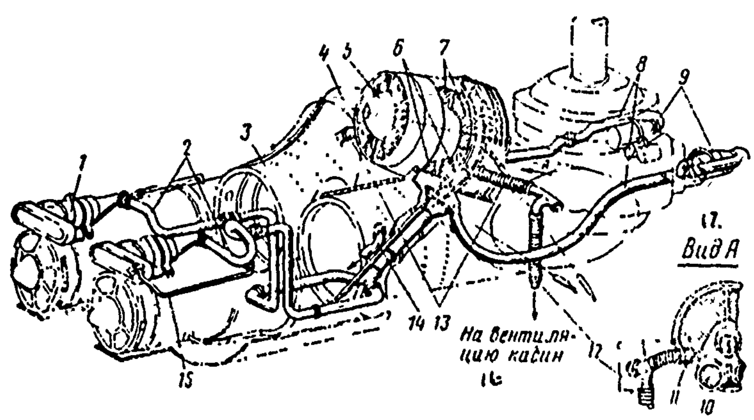

Fig. 71 Cooling System:

Key: 1) jacket with parts for cooling starter-generator, 2) air pipes for starter-generator cooling, 3) exhaust pipe jacket, 4) exhaust pipe, 5) fan, 6) engine oil radiators, 7) main reduction gear oil radiators, 8) air flow lines for cooling alternating current generators, 9) air flow lines for cooling hydraulic pumps, 10) central hole, 11) air flow line for cooling exhaust pipe, 12) air flow line for cabin ventilation, 13) air flow line for exhaust pipe jacket, 14) air flow line into cabin heating system, 15) air flow line to compressor, 16) to cabin vent, 17) view

The fan is connected to the main reduction gear by a universal joint shaft (Fig. 72).

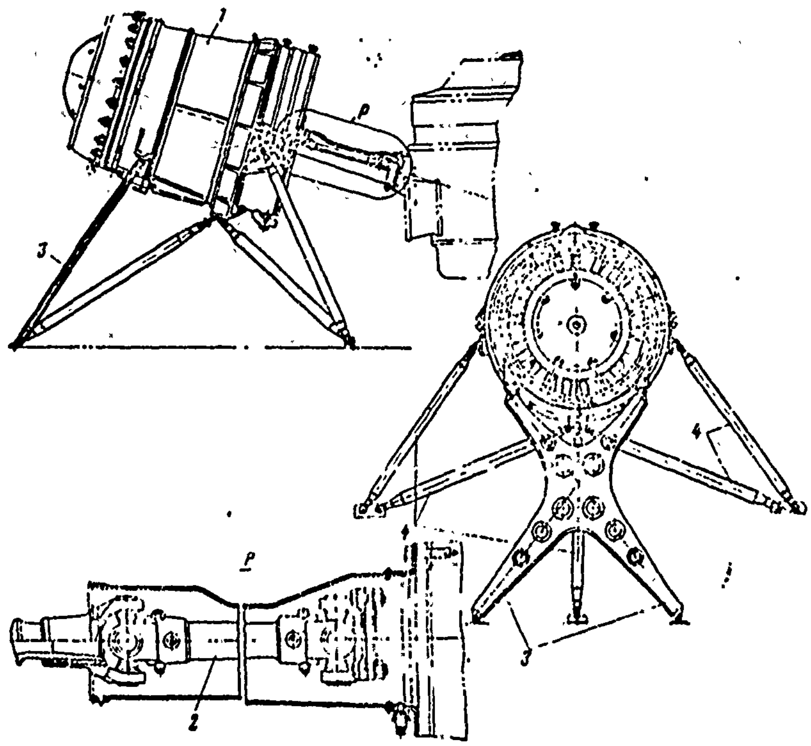

Fig. 72 Fan Installation:

Key: 1) fan, 2) universal joint shaft, 3) fan fastening cross, 4) struts

The flow portion of the fan (Fig. 73) is formed out of the circular hollows of the guiding apparatus body 7 and fan drive body 9. Blades 6 with changeable angles of installation of installed in the circular hollow of the guide apparatus. The blades of fan rotor disc 8 are stationary. Stationary aligning blades 10 are located behind the fan.

Air flows from the space of the aligning blades into the circular space formed by outer 11 and inner 12 diffusors and then into the radiators.

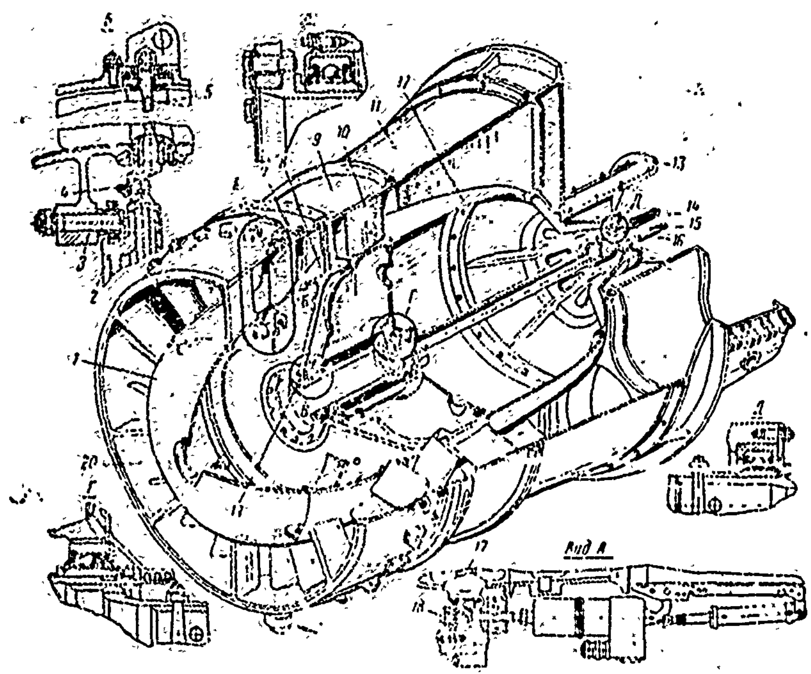

Fig. 73 Fan Block:

Key: 1) fairing body, 2) ring, 3) eccentric pin, 4) rod with bearing, 5) blade shaft, 6) rotating blade, 7) guiding apparatus body, 8) fan rotor disc, 9) fan drive body, 10) fan drive body aligning blades, 11) external diffusor, 12) internal diffusor, 13) radiator fastening body, 14) bearing race, 15) ball bearing, 16) fan drive spring, 17) blade axis, 18) linkage, 19) fan drive shaft, 20) cover with lock

The Oil System

Each engine in a helicopter has an independent oil system and therefore in case of damage to one of them, the other continues to service the engines. The oil system of each engine (Fig. 74) consists of an oil tank 14, oil radiator 2 with a by-pass valve, a filter-chip detector, pipelines, frame and two drain valves 5 which are made in one block.

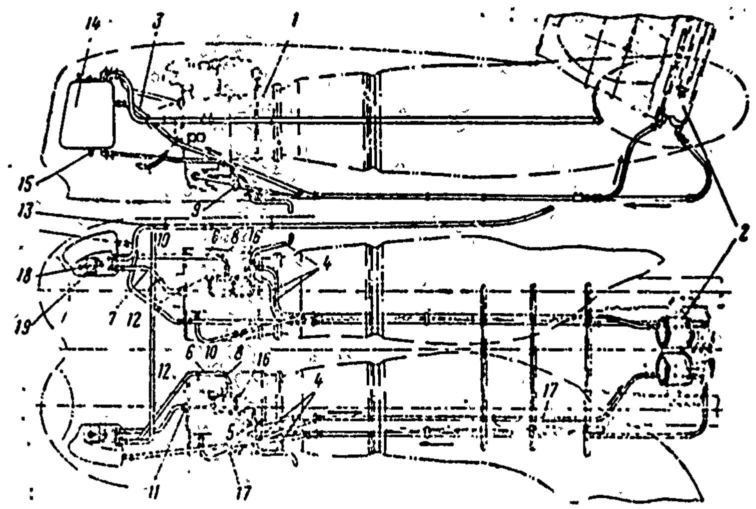

Fig. 74 Assembly Diagram of Engine Oil System

Key: 1) engine, 2) oil radiator, 3) cool oil line, 4) drain line, 5) drain valve block, 6) oil line from tank to engine, 7) engine vent line, 8) thermometer measuring temperature of oil entering engine, 9) filter-chip detector, 10) oil line into engine oil pump, 11) engine breather centrifuge, 12) drain cock on engine, 13) oil tank vent line, 14) oil tank, 15) valve for draining oil from tank, 16) valve for draining oil from lines feeding oil to engine, 17) hot oil line, 18) oil measuring gauge, 19) filler neck

Drain lines 4 from these valves run along the walls inside the fuselage and pass outside and downward outside the skin. Drainage of feed oil into the engine is accomplished through valves 16 and out of the oil tank through valve 15.

The temperature and pressure of the oil are measured with sensors.

The oil system of the main reduction gear and free turbines (Fig. 75) consist of two radiators 2, by-pass valves 3 and pipelines for feeding oil into the main reduction gear and turbines.

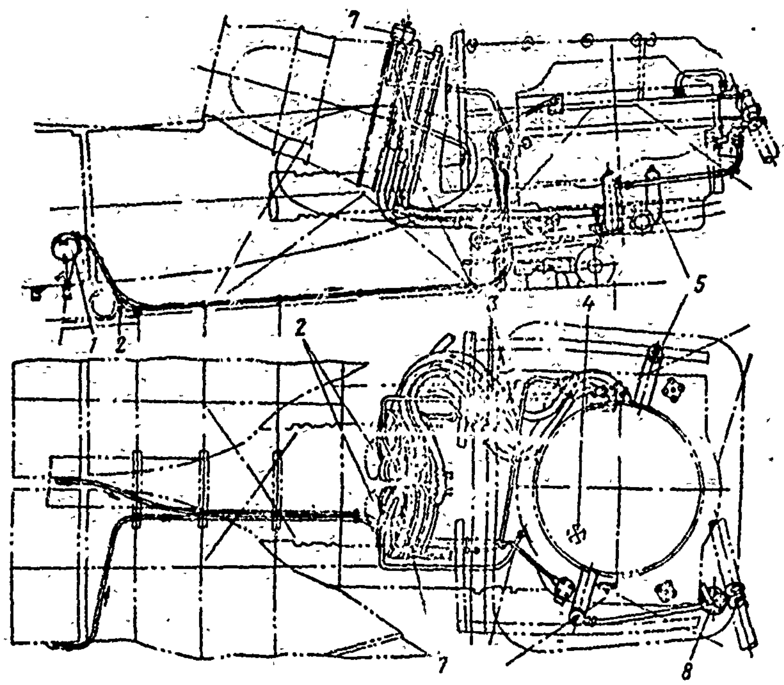

Fig. 75 Main Reduction Gear Oil System

Key: 1) free turbine oil pump, 2) oil radiators, 3) by-pass valves, 4) drain cock, 5) filler necks, 7) breather tank of free turbine transmission, 8) reduction gear breather tank

Oil is pumped by the oil pumps from the main reduction gear and is forced through the by-pass valves into the upper hoses of the oil radiators.

The by-pass valves are intended to prevent the radiators from being burst under high pressure in the case the oil thickens at low temperatures.

Oil flows out of the radiators through the lower pipes and drains into the main reduction gear housing by gravity flow.

A suction pump is installed in the housing of the free turbine and it feeds oil into the main reduction gear housing.

Oil is fed to the shaft bearings and the free turbine by a pump which is mounted inside the reduction gear.

Engine Starting and Control System

The engine can be started by an airport electric power source or with the on-board storage batteries. The engine is started by the starter-generator when the starting button is pressed.

Control of the starting is effected by a set of components in the automatic starting system.

The second engine is started from the generator of the working engine, similarly to the starting of the first engine.

The main system of controlling turboprop engines is the system for automatically maintaining the number of main rotor revolutions, which is provided by free turbine rpm regulators and revolution sychronizers.

Engine shutdown (Fig. 76) is accomplished with a lever located in the pilot's cockpit, for which the lever is moved upward until it stops. The shutdown lever is connected to the engine fuel pump-regulator lever with cables and rods.

The "pitch-gas" system connects control of the engines with control of the main rotor collective pitch in a common lever. The "pitch-gas" lever is kinematically connected with the rotor control assembly and is alsc connected with the fuel feed levers on the pump-regulators which are located on the engines. When the "pitch-gas" lever is moved upward, the collected pitch of the main rotor is increased and the engine is simultaneously transferred to a greater power rate. The possibility for correcting control of the engines is provided in the "pitch-gas" lever. Correction is necessary for establishment of the most efficient number of main rotor revolutions according to flight configurations, especially during changes in flight altitude. To change the number of main rotor revolutions while maintaining a given collective pitch value, the rotating correction handle is kinematically connected only with the fuel feed lever on the pump-regulators. When this handle is turned in a clockwise direction (looking

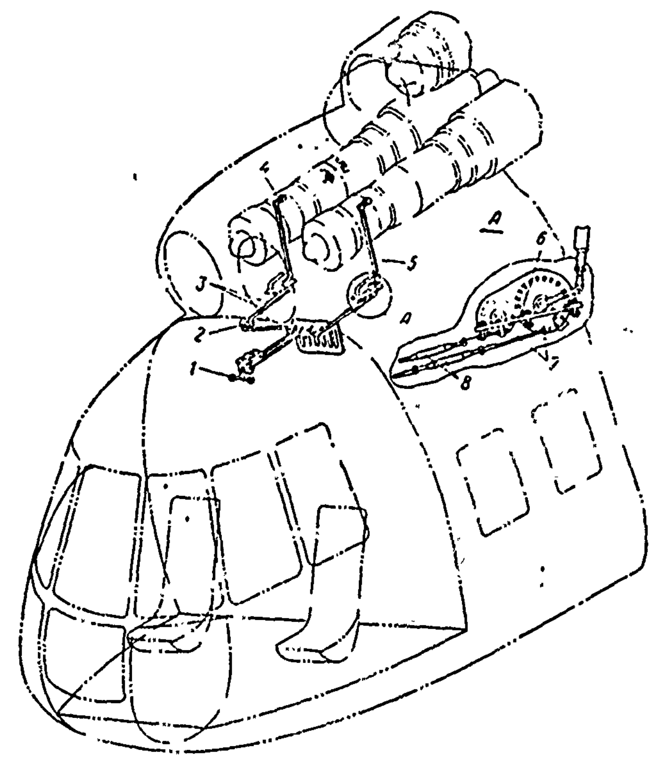

Fig. 76 Diagram of Engine Shutdown Controls:

Key: 1) engine shutdown lever, 2) roller, 3) cables, 4) fuel pump-adjustor lever installed on the engine, 5) engine shutdown rod, 6) bracket, 7) rollers, 8) turnbuckles

down on the face of the "pitch-gas" lever), the engine is transferred to a lesser power rate.

The pilot can realize a transfer from the automatic rpm maintaining system to the "pitch-gas" system and back by turning the correction handle.

When the correction handle is turned to the right, the automatic rpm maintaining system is working. When the correction handle is turned to the left, the automatic regulation system is disengaged and the "pitch-gas" system is engaged.

Multiengine power installation together with the united "pitch-gas" control, separate engine controls are installed on the helicopter allowing testing of each engine to be conducted without changing the collective pitch of the main rotor. The separate control is accomplished by levers which are installed on a common bracket of the "pitch-gas" lever. These levers are connected with the engine fuel pumps by rods.

Engine and Fan Cowling

Cowling of the engines and fan is performed for the purpose of decreasing their frontal resistance and creating the necessary configurations in the air intake and exhaust installations.

The cowling consists of the following parts (Fig. 77): air intake, engine compartment cowling, air passage tunnel to fan, fan compartment cowling, reduction gear compartment cowling and cowling tail compartment.

The cowling is designed in such a manner that the engines, reduction gear and all accessories located in the upper parts of the helicopter can be serviced under away-from-airport conditions.

The cowling design must provide the possibility for assembling and disassembling the engines and main reduction gear without removing the cowling covers from the fuselage.

The covers of the engine, reduction gear and tail compartments of the cowling which open have special areas providing the possibility for service personnel to be located on them. Each area is opened by a hydraulic cylinder or manually, when the hydraulics are not working. The under-

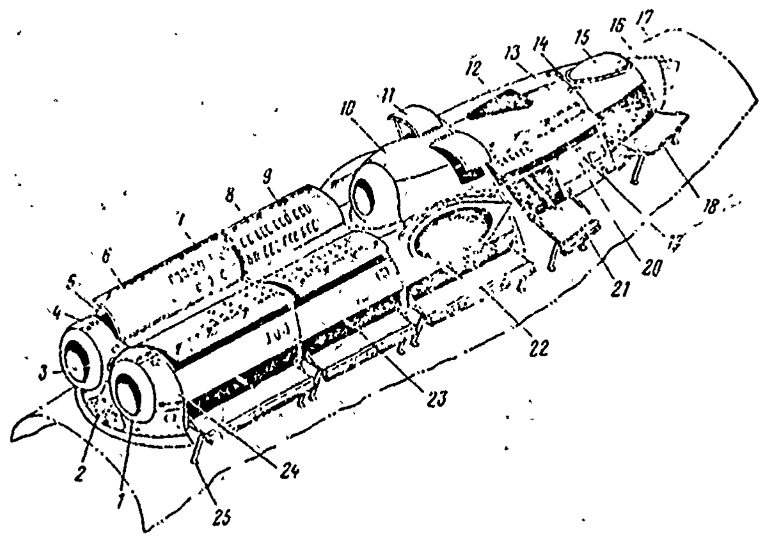

Fig. 77 Cowling:

Key: 1) air intake, 2) front hatch, 3, 4 and 7) handles, 5) cover support, 6) front compartment cover, 8) middle compartment cover, 9) gill slits, 10) fan cowling, 11) cover, 12) opening for reduction gear shaft, 13) reduction gear cowling, 14) hatch cover, 15) hydraulic block fairing, 16) cowling tail fairing, 17) air passage tunnel, 18) cowling tail fairing door, 19) hatch cover, 20) reduction gear cowling cover, 21, 22) doors, 23) door control hydraulic cylinder, 24) oil tank installation nitch, 25) door rest

cowling space is divided into compartments for the engines and a reduction gear compartment with fireproof bulkheads and shields. This construction of the cowling creates the best conditions for extinguishing a fire if one should occur.

The air intakes have nitches with platforms for installation of the engine oil tanks.

An anti-icing system is mounted in the noses of the air intakes to prevent their icing.

Air transfers are installed between the air intakes and the front flanges of the engines. The design of the air transfer connections with the air intake and the engine must

provide the possibility for movement of the engine relative to their supports while it is working. The engine air intake fairings are heated with hot air which flows out of the engine compressors (Fig. 78). The hot air moves along hose 4 to air switch 5 which has an electric mechanism. When the anti-icing system is turned on, the air switch opens and allows air to flow along hose 3 to collector 1. There are holes in the collector through which air moves into the slot between the coll(?)tor and the skin of the engine intake installation fairing, heating the intake tunnel of the engine.

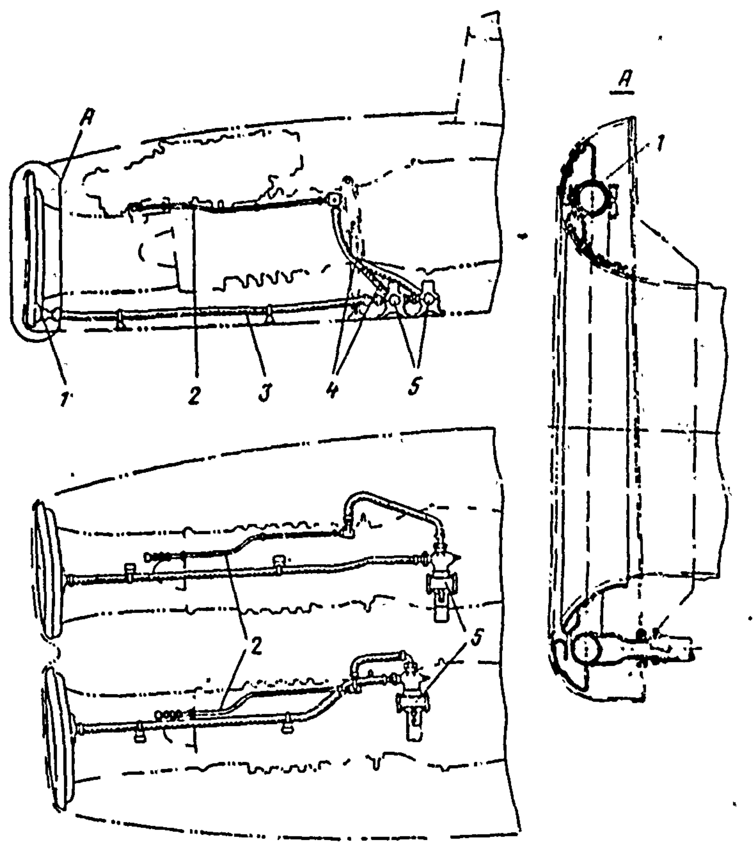

Fig. 78 Anti-Icing Installation of the Engine Air Intakes:

Key: 1) collector, 2) line for heating air intakes in fuel system regulator, 3 and 4) hoses, 5) air switch with electrical mechanism

Fire Extinguishing System

For extinguishing fire in the area of the power plant, the upper fuel tank and heater compartment, a centralized fire extinguishing system is provided on the helicopter (Fig. 79) and consists of fire extinguishers filled with freon 114 B_2 liquid, check valves, a block of anti-fire valves, pipelines, sprayers and a manifold, and also a signalling system.

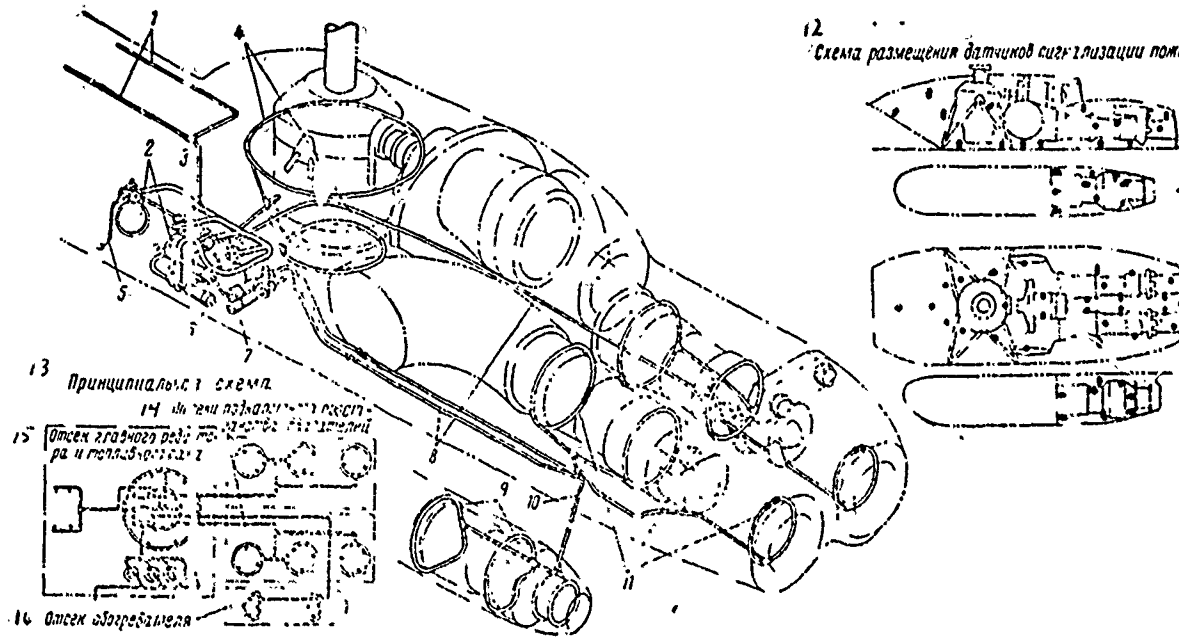

Fig. 79 Fire Extinguishing System:

Key: 1) sprayer lines to fuel tank compartment, 2) cylinders, 3) check valves, 4) sprayer rings in reduction gear compartment, 5) line carrying fire extinguishing liquid overboard, 6 and 7) two-section valve blocks, 8) line carrying fire extinguishing liquid into engine compartment, 9) sprayers in heater compartment, 10) line carrying fire extinguishing liquid to heater, 11) sprayer rings in engine compartments, 12) diagram of fire signalling sensor location, 13) functional schematic, 14) compartments of engine under-cowling space, 15) main reduction gear and fuel tank compartment, 16) heater compartment

All the protected space is divided into compartments: the right engine under-cowling space compartment; the left engine under-cowling space compartment; the main reduction gear and fuel tank compartment and; the heater compartment.

Each compartment has its own group of signalling mechanism which consists of sensors and an anti-fire valve.

The fire extinguishers are divided into two stages of triggering. The first stage is automatic. When a fire appears in one of the compartments, an electric current is generated in the signalling mechanisms of this compartment, as a result of which the corresponding display on the electrical panel in the pilot's cockpit is lit up and the required anti-fire valve is opened. The anti-fire valve closes the electrical circuit of an explosive cartridge located in the head of the fire extinguisher. The cartridge, exploding, opens the lock and the fire extinguisher composition is forced into the area of the fire.

The first stage of tanks, besides being automatically triggered, can also be brought into action by pressing the corresponding button.

The second stage of tanks is triggered only by the pilot's pressing on a button after he receives a signal on the light display indicating a fire.

Check valves are installed on the heads of the fire extinguishers, and therefore, the fire extinguishing composition, while being forced into the area of the fire, does not move into earlier-emptied tanks.

Sprayer rings made of stainless steel and having holes along their perimeter are installed in the engine compartments. The fire extinguishing composition is discharged through these holes.

Sprayer rings and tubes are installed in the compartments of the main reduction gear, above the fuel tank container and in the heater compartment.

Manual fire extinguishers are installed in the cargo cabin.

In addition to a fire excinguishing system, anti-fire bulkheads are installed in the engine and fan compartments.

The under-cowling space is divided into right and left sections by a longitudinal anti-fire bulkhead.

The engine is separated from the reduction gear compartment by a transverse anti-fire bulkhead.

The anti-fire bulkheads are made of titanium and consist of a form and double skin.

Tightness between the faces of the panels is accomplished with rubber molding. The holes for passage of the power shafts of the engines are sealed with special boots.

Section 6

The Helicopter Transmission

Purpose of the Transmission and Requirements Outlined for It

The purpose of the transmission of helicopters consists of transmitting the torque moment from the engine to the main and tail rotors and to auxiliary accessories.

One of the most important requirements for the transmission is its high reliability in work, since breakage of transmission elements during flight will lead to serious consequences. Therefore, all parts of a transmission are carefully calculated and studied. The maximum torque moment transmitted by the engine transmission to the main and tail rotors is taken as a design value. The changing forces and moments acting on the transmission are also considered.

Transmission shafts are computed for bending and warping oscillations for all engine power settings for the purposeof eliminating the possibility of resonance.

The transmission is tested for dynamic strength. During reserve tests, the resistance to wear is checked in all elements of the transmission.

Corresponding compensators which exclude additional load on its elements must be provided in the transmission. The additional load may arise if parts of the assembly on which the shaft supports and reduction gear are mounted become deformed.

The location of the transmission must provide convenient assembly and disassembly of its components and also convenient access to it for inspection and servicing during operation.

Layout of the Transmission

The helicopter transmission consists of the following major parts and components:

1) Main reduction gear with the main rotor fastened onto its low-revolution shaft;

2) Intermediate reduction gears for changing the direction of drive or transmitting engine power along two or more directions;

3) Tail reduction gear with the tail rotor hub fastened onto the nose of its shaft;

4) Idling clutch;

5) Main rotor brake;

6) Shafts: main, tail and synchronizing;

7) Shaft connections: splined and elastic sleeves, universal joint;

8) Shaft supports;

9) Reduction gear supporting frames.

Fig. 80 shows the transmission of a single rotor helicopter. The transmission consists of three reduction gears and a number of shafts connecting the reduction gears together and with the engine. The brake, which is intended to speed up stoppage of main and tail rotor rotation, is also included in the transmission system.

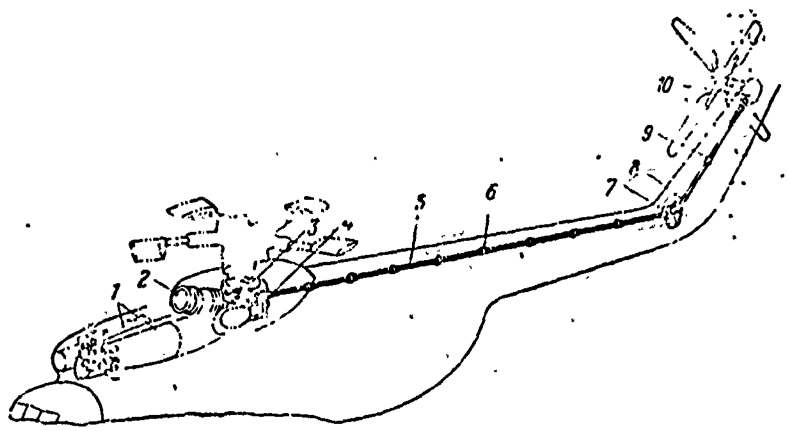

Fig. 80 Helicopter Transmission:

Key: 1) engine, 2) fan, 3) main reduction gear, 4) transmission brake, 5) tail shaft, 6) tail shaft intermediate support, 7) intermediate reduction gear, 8) tail portion of shaft, 9) intermediate support of shaft tail portion, 10) tail reduction gear

Engine power is transmitted into the main reduction gear through the main shaft. The main reduction gear is fastened to the fuselage by the reduction gear frame. Distribution of power takes place in the main reduction gear: the largest part of the power is transmitted to the main rotor and a lesser part is transmitted to the rear output of the main reduction gear which is intended to drive the tail rotor. The transmission brake is located on the rear output of the main reduction gear and is brought into action from the pilot's cockpit. The idling clutch is installed on the main reduction gear input. When the engine is stopped in flight, the idling clutch disengages the transmission from the engine to the main rotor and the latter transfers into the autorotation configuration.

The tail propeller is connected to the main reduction gear with the tail transmission. The tail transmission includes the intermediate and tail reduction gears which are connected together and to the main reduction gear by the tail shaft.

The front end of the tail shaft is fastened to the main reduction gear output.

In connection with the fact that misalignment can occur during manufacture and assembly of the fuselage and the tail boom and with the fact that deformation in the helicopter body during flight and on the ground will cause deformation of the tail shaft, the separate parts of the tail shaft are connected together and to the reduction gears with splined sleeves which allow changes in the angular and linear placements of one of the reduction gears relative to another.

The intermediate reduction gear 7 is connected by the inclined end portion of the tail shaft to tail reduction gear 10 on the shaft of which the tail rotor is fastened.

The tail reduction gear provides a change in the direction of transmittal of the torque moment from the end portion of the tail shaft to the tail rotor and a change in the number of revolutions. Besides this, the tail reduction gear has a mechanism for controlling the pitch of the tail rotor.

The Main Reduction Gear

The main reduction gear is intended to transmit the torque moment from the engine to the shafts of the main and tail rotors.

Forces and moments absorbed by the reduction gear housing are transmitted to the fuselage with a frame (Fig. 81).

The reduction gear has a high degree of gear reduction which is necessitated by the low rpm's of the main rotor and by the high rpm's of the engine free turbine.

The design of the reduction gear includes:

1) Idle clutch;

2) Drive to tail rotor;

3) Drive to accessories: revolution regulator, hydraulic pumps, main and backup hydraulic system for control of the helicopter and to the revolution counter.

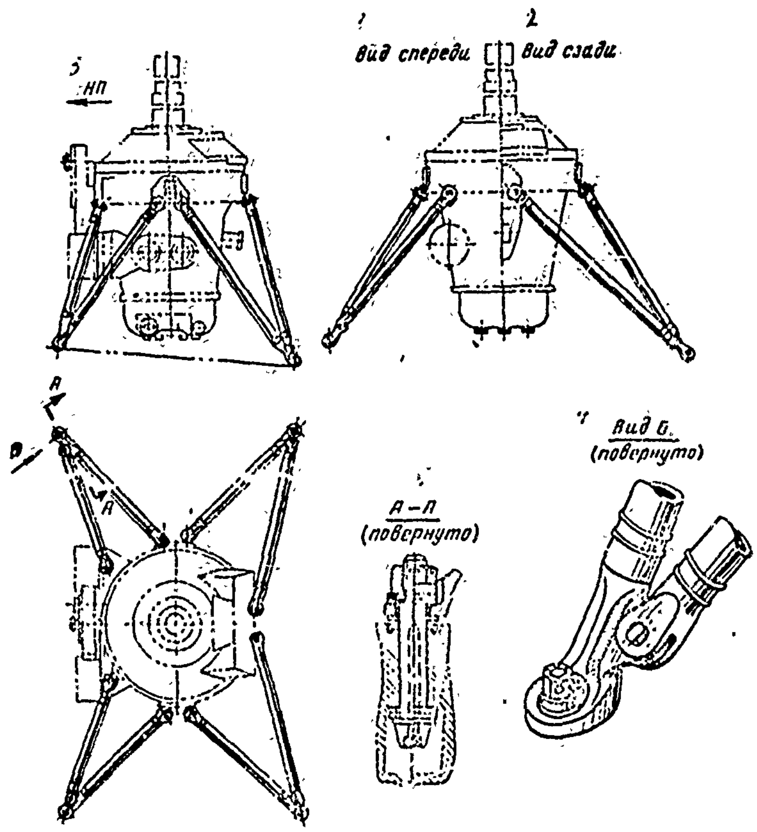

Fig. 81 Main Reduction Gear Frame:

Key: 1) view from the front, 2) view from the back, 3) direction of flight, 4) view B (turned), 5) A-A (turned)

The kinematic diagram of the main reduction gear is shown in Fig. 82.

Power is transmitted from the shaft of each engine turbine through the idling clutch to a cylindrical toothed wheel.

The power is transmitted through a shaft to a conic pair of geared wheels. Power is then transmitted through the driven conic toothed wheel to the upper part of the reduction gear which consists of two stages of planetary gears. From the second planetary stage, power is transmitted to the main rotor shaft.

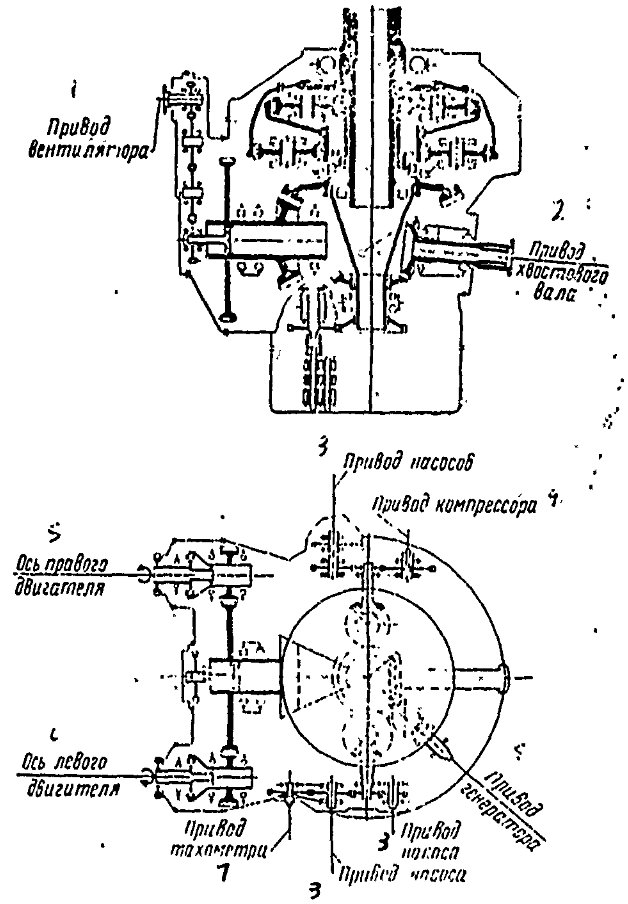

Fig. 82 Kinematic Diagram of the Main Reduction Gear:

Key: 1) fan drive, 2) tail shaft drive, 3) pump drive, 4) compressor drive, 5) right engine shaft, 6) left engine shaft, 7) tachometer drive, 8) generator drive

In the interest of safety, a system of disengaging the transmission from the engine for free rotation of the main rotor in case the engine fails is used on helicopters.

All the power for the main and tail rotors, as well as for the drive of the auxiliary components is transmitted through the idle clutch (free-wheeling clutch).

The idle clutch consists of an outer ring and a star, between which are located a retainer with cylindrical rollers. The retainer serves to prevent the rollers from becoming misaligned relative to the working surfaces of the star and the outer ring, and alsoto ensure the simultaneous engagement of all rollers. The retainer has projections on the side of the outer ring which limit the play of the rollers and the retainer when the clutch is disengaged, resting in limiting projections on the face of the star when this happens.

The driving part in the idle clutch is the star and the driven part is the outer ring.

Engagement of the idle clutch is effected automatically when the star is rotated in a clockwise direction, as the result of the roller's wedging between the working surfaces of the star and the inner surface of the outer ring when the number of star revolutions is equalized with the number of outer ring revolutions. Disengagement of the idle clutch takes place automatically when the number of star revolutions becomes less than the number of outer ring's revolutions.

Working surfaces of the star and the outer ring are made in a slight cone for the best distribution of load on the rollers when the ring is deformed under load.

Oil feed to the reduction gear for lubrication and cooling of the sliding parts is accomplished by an oil pump which is located inside the oil sump. The oil pump has two stages: the forcing one and a transfer one.

An oil filter and a reduction valve limiting the maximum oil pressure in the reduction gear oil system are located on the outlet of the force stage of the oil pump.

Heated oil from the reduction gear flows into the oil radiator where it is cooled to the required temperature. Oil is pumped into the oil sump from the radiator by the transfer stage of the oil pump. The body of the oil sump has an inner bulkhead for the purpose of dividing the areas of cool and hot oil.

There are breather holes in the upper portion of the bulkhead and holes for collecting residues of the hot and cold oil in the lower part. The breather holes are necessary to equalize air pressure in the compartment.

A magnetic plug is screwed into the bottom of the oil sump body to trap steel particles which get into the oil.

The Intermediate Reduction Gear

The intermediate reduction gear is intended to change direction of the tail shaft. This change is achieved by a pair of conic toothed wheels. The torque moment from the main reduction gear is transmitted through the intermediate reduction gear to the tail reduction gear.

The intermediate reduction gear consists of the following parts: housing 11, driving toothed wheel cup 4, driven toothed wheel cup 12 and breather 10 (Fig. 83).

The housing has two bore holes in which the cups and supports of the drive and driven toothed wheels are inserted. There are holes in the upper part of the housing for the breather and the oil measuring gauge. A sensor for an electric thermometer showing the temperature of the oil in the housing is installed in the lower part of the housing. A drain hole closed with a plug is located in the extreme bottom part of the housing. There is a hole in the side wall for the purpose of inspecting the toothed wheels while the reduction gear is being turned at the manufacturing plant (this hole is closed with a plug).

The supporting cups of the driving and driven toothed wheels are identical in construction. Clearances between the conic teeth of the wheels are adjusted by means of selecting the proper thickness for steel adjusting rings 15 which are inserted between the cups and the reduction gear housing.

In that the cups are manufactured out of a magnesium alloy, steel races are pressed into them and fixed with pins to create reliable support for the bearings. These races are bored while in the part. Forces from each toothed wheel are absorbed by three bearings -- two roller bearings absorb only the radial load and the third, a radial-support one, absorbs only the axial load. In order to ensure that it absorbs only the axial load, the radial-support bearing is placed in the cup. The bearing unit is tightened by nut 5 through spacing bushing 7 and flange 6 which is installed on splines of the tail gear.

To prevent oil leaks along the shafts, their outputs are protected with labyrinthine sealings which are protected from dust by felt seals which are impregnated with graphite lubricant.

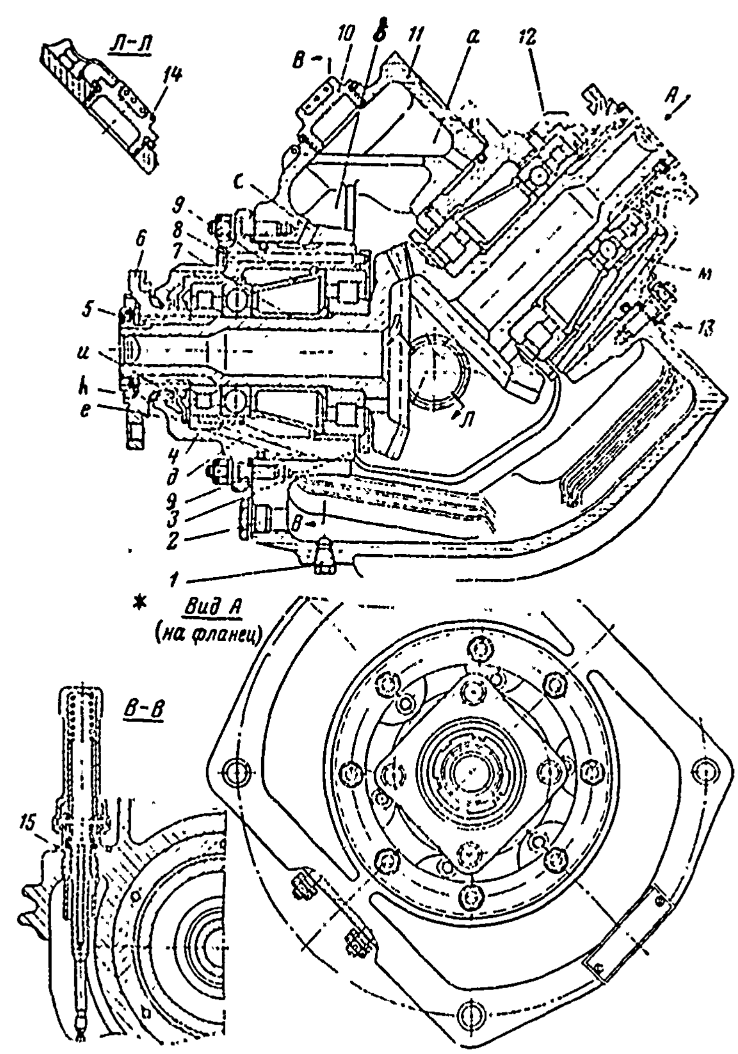

Fig. 83 Intermediate Reduction Gear:

Key: 1) plug, 2) plug, 3) roller bearing fastening flange, 4) driving toothed wheel cup, 5) nut, 6) splined flange, 7) inner spacing bushing, 8) bolt, 9) outer spacing bushing, 10) breather, 11) housing, 12) driven toothed wheel cup, 13) adjusting ring, 14) plug, 15) oil measuring gauge, a)and b) pockets, c),d) and m) canals, e) and g) circular spaces, h) interlabyrinthine space, u) bearing space, * view A oward the flange)

In light and medium helicopters, splashing lubrication (foaming) is used in the intermediate reduction gear.

The driving toothed wheel, whose hub is partially submerged in oil, creates an oil emulsion in the reduction gear housing when it is turned, providing lubrication of the wheel teeth.

Splashed oil is trapped in pockets "a" and "b" which are cast in the housing for the purpose of providing lubrication of the toothed wheel bearings. Each of these pockets is located higher than the bearing whose lubrication it provides. Oil flows from the pocket by gravity flow along a canal "c" into the circular hollow "e" and through canal "d" in the cup in the circular hollow "e". The oil is then directed toward the paired bearings, flows to the second roller bearing and drains from there into the housing.

Oil flows from hollow "u" through special holes in the cup. From the interlabyrinthine space "h", oil drains through holes similar to the passage of canal "m".

There is an oil measuring gauge for monitoring the oil level in the upper part of the reduction gear. Access to the gauge is through a hatch.

The location of the intermediate reduction gear inside the circular boom makes its cooling more difficult. To improve its cooling, the reduction gear housing is thinned not only outside but also inside. Louvers in the upper and lower hatches of the tail boom afford ventilation of the place where the intermediate reduction gear is located.

Breather 10 is installed in the upper part of the reduction gear to bleed off excess air pressure. The breather consists of a number of labyrinthine passages which block oil flows to the outside in case of foaming. Screened washers with inserts between them which protect the reduction gear from the penetration of dust into it during intake of air from the outside are installed in the breather head.

In heavy helicopters, the intermediate reduction gear has a main system with forced oil feed and a backup system -- a foaming oil stream which provides lubrication of the bearings in case the main oil system fails.

Forced oil feed to the bearings and toothed wheels by an oil pump is used to extract heat generated in the reduction gear. The oil pump is driven by the driven gear shaft. Oil

leaving the pump flows into the oil filter, and flows from it along passages in the housing and cups to jets for lubricating the corresponding parts. Heat extraction from the housing is provided by a fan.

Tail Rotor Reduction Gear

The reduction gear is intended to rotate the tail rotor at the required number of revolutions. Rotation is accomplished by a pair of conic toothed wheels which are placed at an angle of 90°.

The tail reduction gear (Fig. 84) consists of the following parts: housing, cup with driving toothed wheel, cover with driven toothed wheel and tail rotor control rod.

The housing has three cylindrical borings in which the cup with the driving toothed wheel, the cover with the driven wheel and the tail rotor control rod unit are installed. Besides this, there are a number of holes in the housing for pins and also threaded holes for the oil gauge sleeve, thermometer and drain and inspection plugs. After unscrewing the inspection plug, the wheel teeth can be checked.

The driving toothed wheel cup (Fig. 85) is a steel part which is fastened to the tail reduction gear housing. There are borings in the cup for ball bearings and for pressing in a sealing sleeve.

A seal to prevent oil leaks and sleeve 2 are assembled in cup 1. The upper end of the sleeve is raised higher than the level of the oil and oil-throwing threads are cut on it The direction of the threads is selected so that when driving shaft 7 is turned, the oil is thrown into the reduction gear housing.

Entry into the hollow between the shaft and sleeve is protected with a rubber seal 4. The driving toothed wheel 5 is seated on splines on a hollow shaft. The splines and seating collar of the shaft are copper plated.

The two-roll ball bearing is prevented from moving in an axial direction by nut 6, which also serves as the disconnecting point for pressing the driving toothed wheel off the shaft during disassembly of the reduction gear. The upper part of the driving toothed wheel shaft is connected to tail reduction gear driving shaft 7 with splines. This shaft, in addition to the splines, rests on ball bearing 3.

which is serviced with lubricant for its entire service period. There are also splines on the other end of the shaft and the tail shaft fits on them.

Out of engineering considerations, the driven toothed wheel is made separately from its hub, to which it is fastened with fitted bolts. The bolt holes in the toothed wheel and in the hub are machined together.

The tail reduction gear driven shaft is fastened in a two-roll ball bearing and connected to the hub of the driven toothed wheel with splines. The tail rotor hub is fastened to the flange on the outer end of the driven shaft.

Splashing lubrication is used in tail reduction gears of light and medium helicopters. It works on the same principle as the lubrication in the intermediate gears.

Two lubrication systems: the main one -- forced, and a backup one -- foaming, are used in the tail reduction gears of heavy helicopters.

Changing the pitch of the tail rotor is accomplished with rod 1 (Fig. 86) which is located inside the tail reduction gear shaft. The rod is activated by a roller chain ritted on star wheel 2, which is mounted on two ball bearings. The rotational motion of the star wheel is transformed into the axial motion of the rod by a multi-course screw 3 and a nut threaded into the star wheel body.

When the star wheel is turned in one direction or the other, the rod will retract or extend outside, changing the pitch of the tail rotor.

Screw 3, which is made of an anti-friction material (bronze, cast iron), is fitted on rod 1 with a cone and key. The rod and screw do not turn together with the nut because the rod and cup 4 are fitted with splines. The rod and cup are connected together with splined sleeve 5 which is mounted on the rod. The sleeve . . . [Translator's note: Pages 118 and 119, including Figures 84, 85 and 86, are missing from the original.]

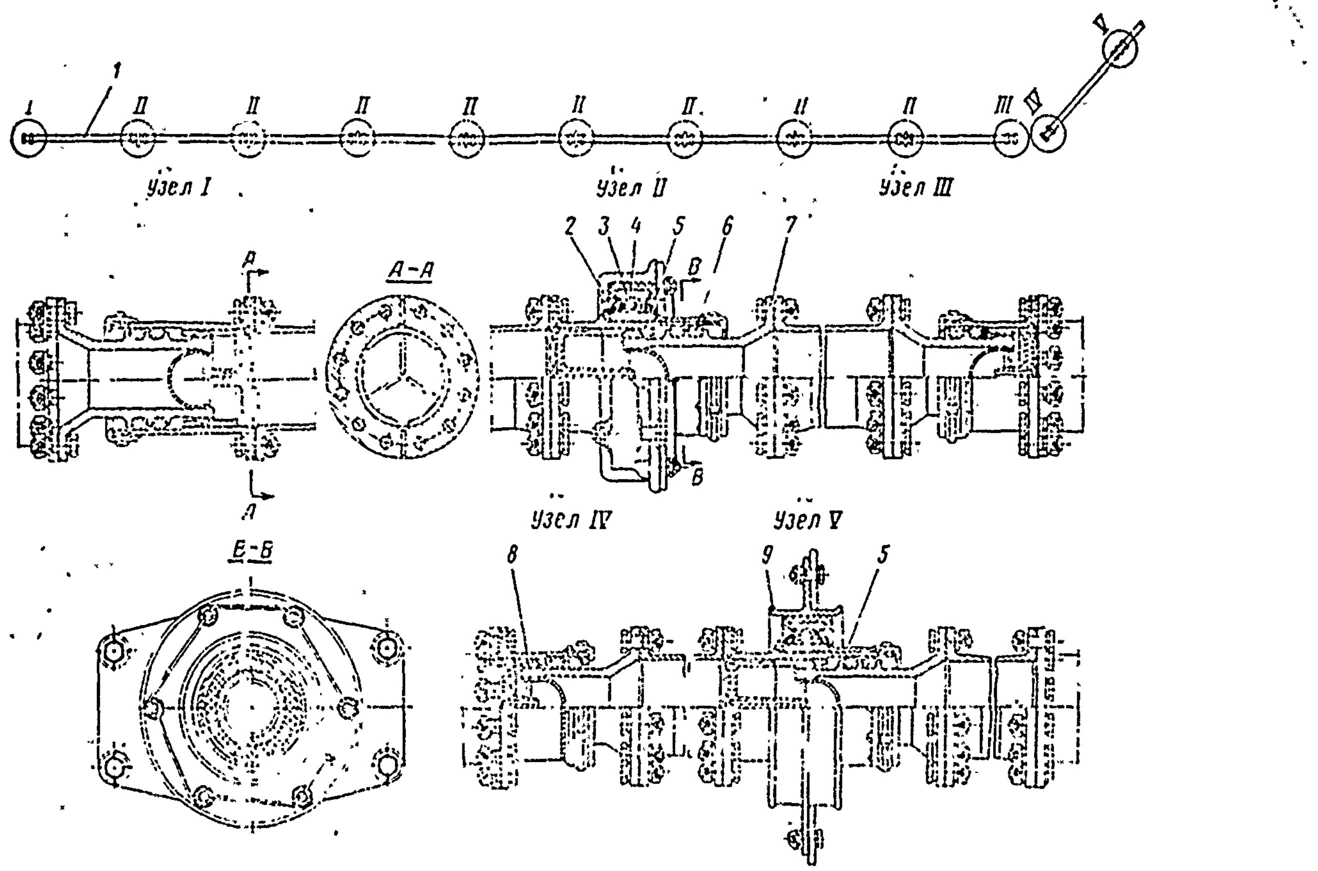

Fig. 87 Transmission Tail Shaft:

Key: 1) tail shaft tube, 2) tail shaft support, 3) tail shaft bearing race, 4) ball bearing, 5) splined sleeve cup, 6) tail shaft sealing rirg, 7) splined sleeve tip, 8) splined sleeve with axial locating shaft, 9) support of shaft tail portion, 10) unit.

The tail shaft has supports 2, on which it is installed on the helicopter. The supports are fastened to fuselage frames of the tail and tip booms A tail shaft support has a recess in which a radial ball bearing is assembled on a rubber ring. The rubber ring is intended to compensate misalignment achieved as the result of inaccurate support installation and also as a shock absorber for elements absorbing lateral shaft oscillations.

The grooved sleeve consists of an outer cup 5 on which long grooves are cut inside and an inner tip 7 with short rectangular grooves. The groove hollows are sealed with

two rubber rings 6. The grooved connection of the sleeve compensates possible misalignment in separate sections of the tube and inaccuracy in lengths of tubes and spans between the supports in the tail boom. It also compensates for differences in temperature expansion of the tail shaft and tail boom of the helicopter.

The grooved sleeve is filled with lubricant with a fitting through one of two holes drilled in the outside flange of the sleeve.

To compensate for assembly misalingments, universal joints (Kardans) are also used (Fig. 88). The universal joints have sliding splines intended to compensate for deviation in the length of the fuselage, tail boom and tail shaft in the process of assembly, and also to eliminate differences in temperature expansion of these units which are manufactured of different materials. When the tail boom is bent under conditions of flight or landing due to the location of the tail shaft higher than the center of the boom, the change in its length is also compensated by the splined connection.

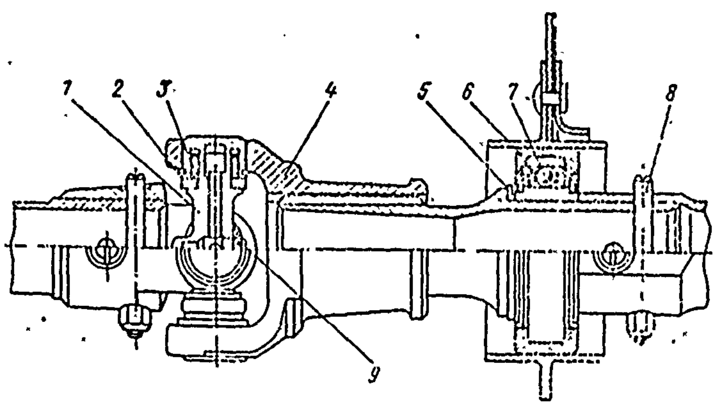

Fig. 88 Tail Transmission Unit (Universal Joint with Splined Connection and Tail Shaft Support):

Key: 1) cross, 2) seal, 3) needle bearing, 4) fork, 5) support ring, 6) rubber ring, 7) bearing, 8) conic bolt, 9) protector valve

Main Rotor Brake

The brake (Fig. 89) is intended to speed up stoppage of the main and tail rotation. Besides this, the brake is used to lock the transmission while parking and conducting assembly and adjusting operations.

The brake is located at the rear output of the main reduction gear where the tail shaft is connected to it.

The brake is of the shoe type with mechanical control effected by a cable. To eliminate overloading the brake parts, a spring limiting force on the cable is included in the control system.

The basic parts of the brake are the mount, shoes and drum.

The brake mount 10 is cast out of aluminum alloy. It is fastened to the main reduction gear body.

The shoes and friction liners made out of ferrado [probably a sintered metal lining] fastened to them are pressed against the bracket by spring 11.

Braking is accomplished by pressing the friction shoes against the brake drum 1, which is fastened to the flange of the tail shaft.

Transmittal of the braking moment from the friction liners to the support pin 13 formed in the bracket is accomplished by hinged links 14 which support the brake shoes on one end. The other ends of the shoes fit into slots in the adjusting screws 4. By withdrawing and extending the screws with hand wheel 3, the clearance between the shoes and the brake drum can be adjusted when the brakes are not tight.

Suspending the shoes on hinged links gives them the freedom to adjust themselves relative to the drum and provide their even wear. The shoes are pressed against the drum by a system of levers and rods. Cable 12 pulls on the hook of spreading lever 9 which is fastened to connections by screw 2 on one of the shoes. When the spreading lever is turned around the screw, spreading rod 5 presses the bottom shoe against the brake drum. When the shoe is pressed against the drum, lever 9 begins to turn not around screw 2 but around the upper end of spreader rod 5, pressing the upper shoe against the drum. The proper position of the spreader rod relative to the lever is assured by spring 6 which passes into a slot in the lever.

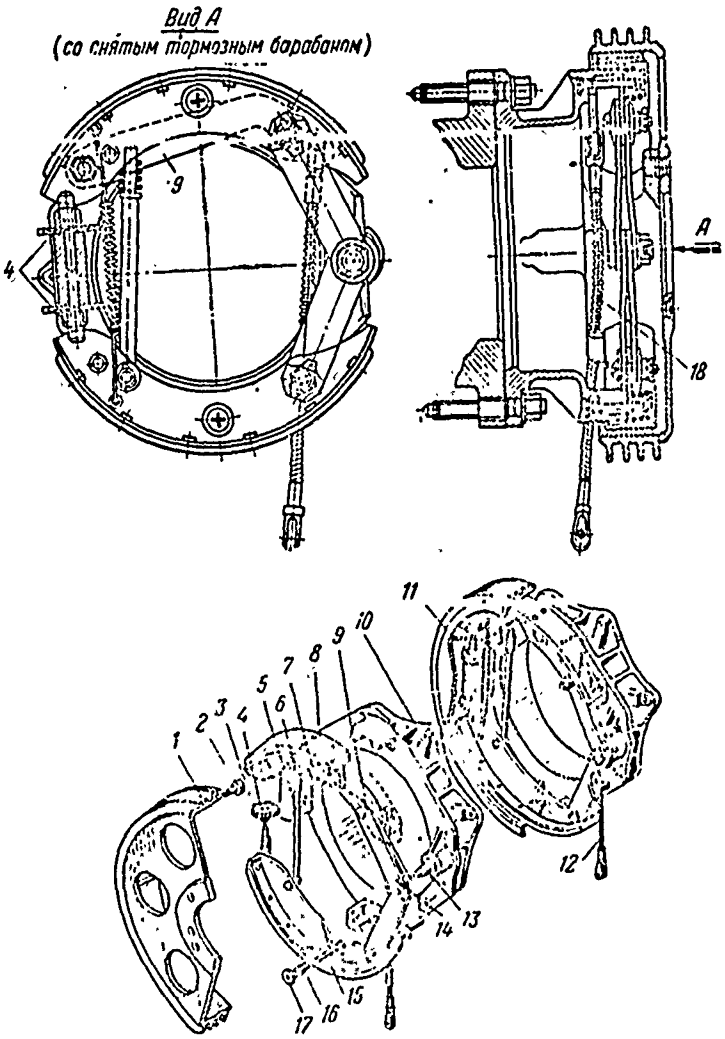

Fig. 89 Main Rotor Brake

Key: 1) brake drum, 2) brake spreading lever screw, 3) brake adjusting hand wheel, 4) adjusting screw, 5) spreader rod, 6) rod spring, 7) brake shoe, 8) friction liner, 9) spreader lever, 10) brake mount, 11) tension spring, 12) brake control cable, 13) brake support pin, 14) brake shoe link, 15) pressure cup pin, 16) pin spring, 17) cup, 18) brake control cable spring

When the cable is not being pulled, it is extended by spring 18 and the shoes are withdrawn from the drum by tension spring 11. When this occurs, the shoes are retracted until they rest in slots in the adjusting screws 4.

Passing between the teeth of the adjusting nuts, the tension spring simultaneously prevents these nuts from unscrewing voluntarily.

Section 7

Control of the Helicopter

General Information

For control of a body in space, it is necessary to be able to change the forces and moments relative to three mutually perpendicular axes (Fig. 90). This requires six independent types of control.

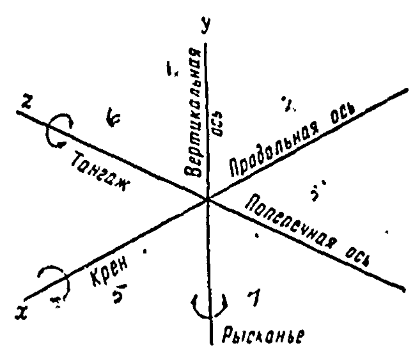

Fig. 90 System of Coordinates

Key: 1) vertical axis, 2) longitudinal axis, 3) lateral axis, 4) yaw, 5) roll, 6) pitch

Four independent types of control are actually necessary for a helicopter. We will look at them.

1. Vertical control is necessary to change the position of the helicopter in space along the vertical. Control along the vertical is accomplished by simultaneously changing the angle of setting of all main rotor blades (control of the collective pitch) which causes a change in the amount of its thrust.

2. Directional control determines the position of the helicopter in space relative to the vertical axis and allows the pilot to guide the helicopter in any desired direction in a horizontal plane.

3. Lateral control includes use of both moments and forces. When the pilot brings lateral control into effect, a rolling moment relative to the center of gravity arises and the helicopter tilts, as the result of which the thrust vector begins to act in the direction of the roll. Therefore, action of the lateral control causes both a roll and lateral movement of the helicopter simultaneously. For a lateral-layout helicopter, the initial action of the lateral control creates only a rolling moment, while in a single rotor helicopter, the sideways force arises simultaneously.

4. Longitudinal control of a single rotor helicopter is similar to lateral control and the pitch moment arises simultaneously with a longitudinal force. In a helicopter of longitudinal layout, action of the longitudinal control creates only the longitudinal moment.

The interaction of forces during control is usually undesirable. For instance, in a single rotor helicopter, an increase in the vertical lift will cause an increase in the torque moment, leading to a necessity for correcting the direct course to maintain the initially assigned direction of flight. This interaction requires a complex coordination of the pilot's actions.

To create the forces and moments necessary for control of the helicopter, the pilot uses the control levers.

Movement of the sticks and pedals on the helicopter corresponds to the established practice of flight in an airplane, whose basis is posited on the principles of instinctive movement of a person to maintain equilibrium while moving and at rest.

Several types of main rotor control are used on helicopters. One of these is control of the blades with control surfaces which are located in the trailing portions of the blades (Kaman servotabs). Deflection of the tab creates a moment relative to the axis of rigidity of the blade, turning it at the corresponding angle.

Control of the main rotor may be effected with Hiller servovanes. The pilot turns the servovanes which are kinematically connected to the blade. Aerodynamic forces arising

on the servoblades creates the necessary force to rotate the main rotor blades. These types of control are used only by certain firms and are not widely used.

We will look at the most widely used kinematic diagram for control: the cyclic pitch lever, acting through a system of rods and rockers (or the autopilot) moves the slide valve of the hydraulic booster and the slave rod of the hydraulic booster, also acting through rods and rockers, turns the blade relative to its axial hinge.

The control stick is located in front of the pilot (Fig. 91) and serves to accomplish the longitudinal and lateral control of the helicopter. In a helicopter, the pilot moves the handle in the direction in which he desires to travel (forward, backward, to the side), changing the cyclic angles of main rotor blade setting through the rotor control assembly. In this manner, inclination of the plane of rotation of the main rotor is brought about and the necessary force and moment are created.

The pedals serve for directional control. To rotate the helicopter to the right, the pilot presses on the right pedal, and for rotation to the left, he presses on the left pedal.

Directional control of a single rotor helicopter is accomplished by the tail rotor. The pilot, pressing on the pedal, changes the pitch of the tail rotor blades. The thrust of the tail rotor is changed, and the necessary moment relative to its vertical axis is created.

In two rotor and multi-rotor helicopters, directional control is effected by the main rotors. The pilot, pressing on the pedals, acts in the necessary manner (depending on the layout of the helicopter) on the angle of main rotor blade setting.

The collective pitch lever is located beneath the left arm of the pilot and serves to simultaneously change the angles of setting of all main rotor blades. As the result of the change in the main rotor blade setting angles, the main rotor thrust is changed and the helicopter moves vertically. When the collective pitch lever is moved upward, the helicopter climbs upward and when the collective pitch lever is deflected downward, the helicopter descends.

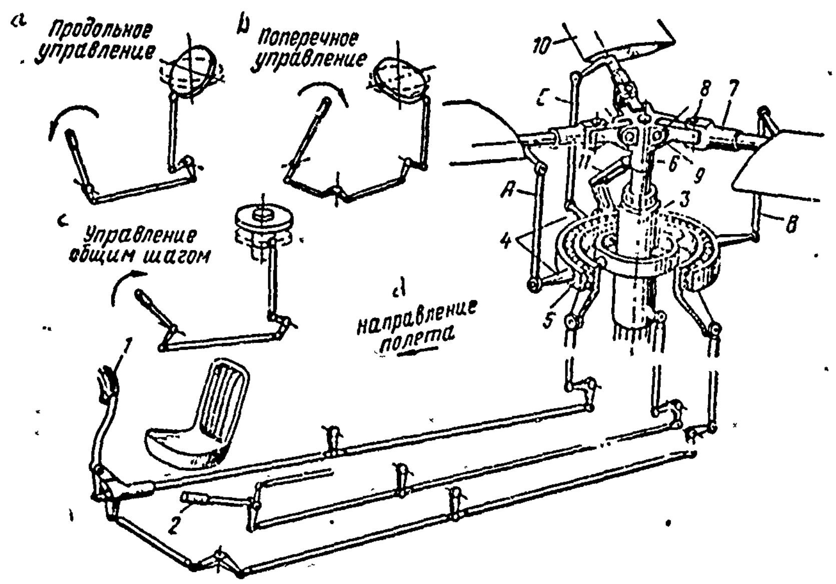

Fig. 91 Helicopter Hub and Control of the Rotor Control Assembly:

Key: 1) control handle, 2) collective pitch lever, 3) movable sleever, 4) axes of rotor control assembly suspension universal joint (rotating together with the hub), 5) rotor control assembly outer ring, 6) hub body, 7) axial hinge axis, 8) vertical hinge axis, 9) horizontal hinge axis, 10) blade, 11) spline hinge;A, B, C) rods connecting assembly outer ring to blades, a) longitudinal control, b) lateral control, c) collective pitch control, d) direction of flight

It is difficult to obtained the desired force gradients on the pilot's controls in helicopters. Forces on the pilot's controls arise from moments relative to the longitudinal axis of the blades. Airfoils for blades and blade configuration are usually selected in such a manner that the moments attempting to turn the blade relative to its longitudinal axis are minimal or equal to zero throughout a wide range of blade angles of attack.

Hinged (axial) moments arise when the blade bends in the process of working, from distortion of the airfoil in space, from forces of friction in the axial hinge bearings and for other reasons. As the result of these reasons, the arising forces can have entirely different values and gradients than those required for sati factory control of the helicopter.

Two types of forces arise in controls: constant and periodic. Periodic forces, with a frequency equal to the number of revolutions, arise as a result of the presence of varying moments on the main rotor blades. If, for example, a hinge moment appears on one of the blades of a three-blade rotor, it will be transmitted to the lever through the rotor control assembly and control system and will cause its movement. The amount of movement will depend on the size of the unequalized moment. Higher frequencies of periodic forces on the control handles may be observed with a fewer number of blades. Higher frequencies of oscillation arise due to periodic changes in the moments on each blade. The moments change as a result of changes in force during horizontal flight, and also as a result of periodic bending of the blades.

Periodic forces acting on the control lever are hinders for the pilot and therefore, inertial dampers are included in the control linkage of light helicopters. The dampers do not allow the changing portion of the hinge moment to reach the control handle. In the contol system of medium and heavy helicopters, in which the amount of hinge moments exceeds the physical possibilities of the pilot, boosters with non-reversing control are installed. In this case, all changing loads are absorbed by the control linkage from the blade linkage to the booster and are not transmitted any further. When the control handle is moved, the pilot overcomes only forces of friction in the linkage parts and in the booster slide valve and ceases to "feel" the helicopter, since the gradient of force on the handle is not proportional to the change in the hinge moment on the axial hinge.

To increase the pilotage properties of a helicopter, artificial force gradients are created on the control handle and pedals.

For this, springs with adjusting mechanisms are introduced into the linkage of the corresponding control. These mechanisms are used to remove extended loads from the control handle and pedals during an established flight configuration.

The following go into the control system of a helicopter:

1) Cyclic pitch control, which connects the longitudinal and lateral control column with the rotor control assembly;

2) Directional control which connects the pedals with the tail rotor (for a single rotor helicopter);

3) Unified control of the "pitch-engine-stabilizer" system where the "pitch-gas" lever is connected by a control system with the slide of the rotor control assembly and levers of the engine fuel pump.

The stabilizer is connected with the slide of the rotor control mechanism by a control link;

4) Separate controls which are connected with levers of the engine fuel pumps;

5) Control of the loading mechanism which are turned on by pressing on electric switches located on the control handle and firing buttons with terminal disengagers on the pedals;

6) Control of the transmission brake which connects the control lever with the lever of the main reduction gear brake.

All levers for controlling the helicopter are located in the pilot's cockpit.

Requirements Outlined for Control of the Helicopter

The basic requirements for control of the helicopter are:

a) The amount of force on the control handle and on the pedals must not exceed allowable limits.

When the control handle and pedals are deflected from the neutral position, forces on them must increase smoothly and be directed toward the opposite side (positive gradient of force on the handle);

b) Necessary control rigidity, determined by conditions of safety from flutter of main rotor blades, wings and empennage must be ensured. "Free travel" cannot be allowed (the therm "free" travel of the control levers is understood to

mean the possibility of moving the lever and pedals without deflecting the control organs as the result of clearances in connections, flexible deformation of the control parts or "slackness" in the cable linkage);

c) The entire control linkage system must have minimum friction in its connections;

d) Independent action of the longitudinal, lateral and directional controls and collective pitch must be provided. Thus, for instance, deflection in a longitudinal direction of a control handle in a single rotor helicopter must not cause rolling or a change in the collective pitch, just as control of the collective pitch must not act on the longitudinal-lateral control;

e) Deformation of the fuselage and other parts of the helicopter along which the control linkage runs must not cause additional forces on the handle and pedals. There must be no seizing or pressure on the linkage and control mechanisms. A change in the angles of attack of the blades during deformation of the construction must provide damping aerodynamic forces to the main rotor;

f) The control handle, pedals and collective pitch lever must have deflection limiters. The limiters are installed immediately on the command levers, or in a case where a differential autopilot is used, on the hydraulic boosters;

g) The angles of control mechanism deflections must have a reserve, i.e. must be greater than those required according to calculations or experimental data;

h) Protection of hinges and sliding parts from dust and moisture and their lubrication must be provided in control system movable connections;

i) All control rods and levers in the cockpit must be so located and have such a form that they do not impair the movement of the pilot during his work, and must not hinder his entry and exit from the cockpit. Besides this, the leg-controlled mechanism in the cockpit must allow adjustment for a pilot's height;

k) Convenience of inspection, assembly and disassembly of the control parts and components must be provided.

Cyclic Pitch Control

Cyclic pitch control consists of a control column, a system of rods and rockers, hydraulic boosters and the rotor control mechanism. One linkage line from the hydraulic booster is intended for longitudinal control and the second is for lateral control (Fig. 92).

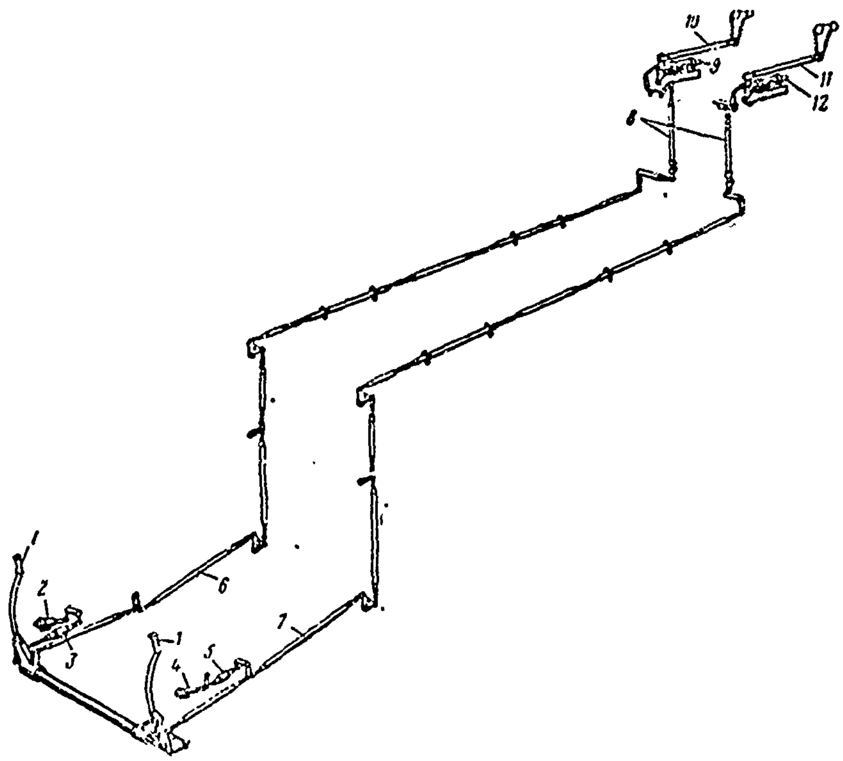

Fig. 92 Diagram of Cyclic Pitch Control:

Key: 1) control handles, 2) electric mechanism, 3) longitudinal control loading spring mechanism, 4) electric mechanism, 5) lateral control loading spring mechanism, 6) longitudinal control rod, 7) lateral control rod, 8) rods with spring device, 9) longitudinal control hydraulic booster, 10) longitudinal control rod, 11) lateral control rod, 12) lateral control hydraulic booster

Spring loading mechanisms which create a gradient force on the control handle are included in the longitudinal and lateral control. Control of these mechanisms is accomplished by a switch which is installed on the upper part of the control handle. This switching installation allows the forces to be removed from the control handle without releasing it.

The manual control column (Fig. 93) is made in the form of a separate part and is fastened to the floor framing of the pilot's cockpit. The manual control handle of medium and heavy helicopters consists of two handles, 1, (of one handle in a light helicopter), with a hinged fastening on pivots 6, tubular shaft 9 and two brackets 7. The lower ends of the handles are connected by rod 10 which passes through the center of the tubular shaft.

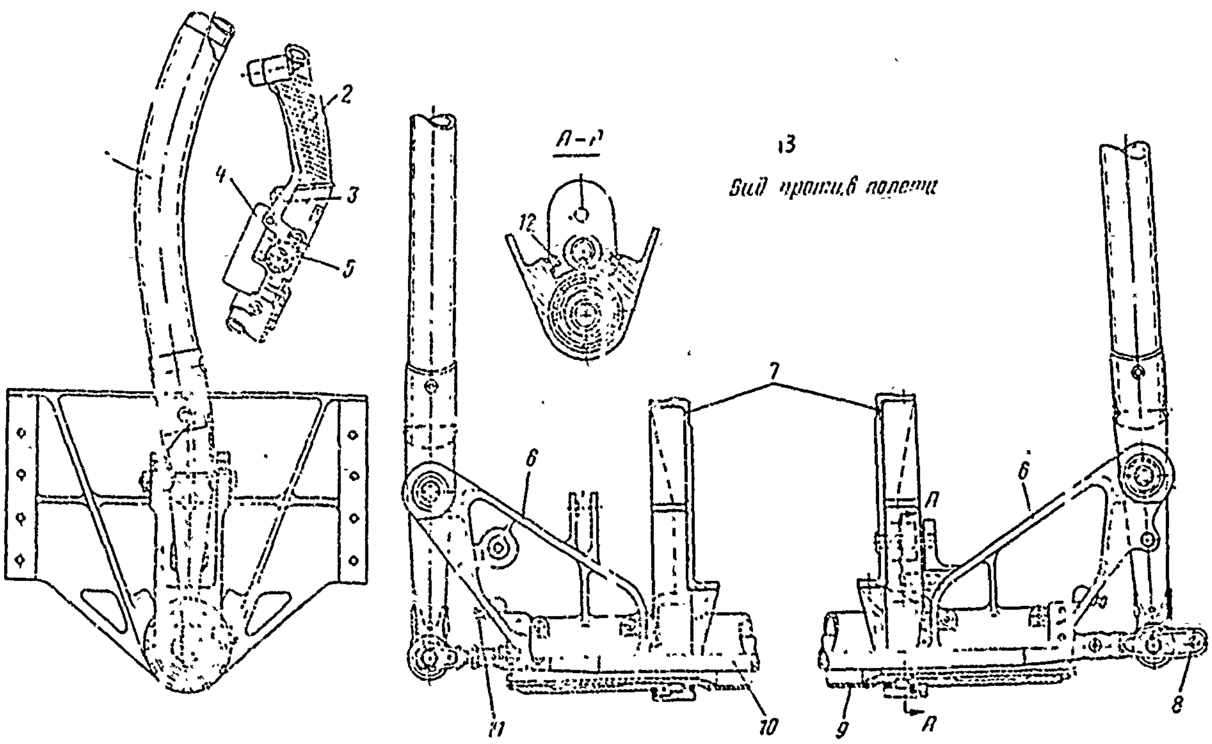

Fig. 93 Manual Control Column:

Key: 1) control lever, 2) handle, 3) trigger for braking main gear wheels, 4) weight, 5) trigger stop, 6) pivot, 7) brackets, 8) rod fork, 9) shaft, 10) rod, 11), 12) limiting bolts, 13) view from the front

The shaft is mounted in brackets on ball bearings. To limit handle deflection in the longitudinal direction, there is a stop which is installed on the pivot. Adjustable bolts 11 which are screwed into pivot 6 serve as the limiters. Bolts 12 which are screwed into both pivots serve as limiters for handle deflection in the lateral direction.

Rod 10 connects the levers in the lateral direction. The lateral control link is connected to fork 8 of this rod. The kinematics of the manual control column provide independent longitudinal and lateral movement of the control lever. The control lever is manufactured of a tube, on the lower end of which is installed a connector fitting and on the upper end of which is installed handle 2. The left handle has trigger 3 for controlling main gear wheel braking. The surface of the handle, on the section gripped by the hand, is covered with rubber by the method of hot pressing. The surface of the handle must have cross-hatching to eliminate the possibility of the pilot's hands sliding during movement of the control lever.

On the upper part of the handle must be mounted a combined control which for the loading mechanisms and three buttons: radio microphone switch, intercom system switch and autopilot disengager. On the lower part of the left hand control handle is installed a button for releasing an externally suspended load.

If necessary, a special weight 4 is installed on the lower part of the control handle. It changes the natural frequency of oscillation of the lever in the lateral direction and eliminates the possibility of its oscillation occurring during flight with the autopilot engaged.

The longitudinal and lateral control rods are laid out from the control column. In the pilot's cockpit, the rods are located beneath the floor and in the cargo compartment, they are located inside it and are covered with special jackets. The rods are connected with rockers in the reduction gear compartment. The rockers are installed on the bodies of the hydraulic boosters. The installation of the longitudinal control hydraulic booster is shown in Fig. 94. The longitudinal and lateral control hydraulic actuators are of a single type and work irreversibly.

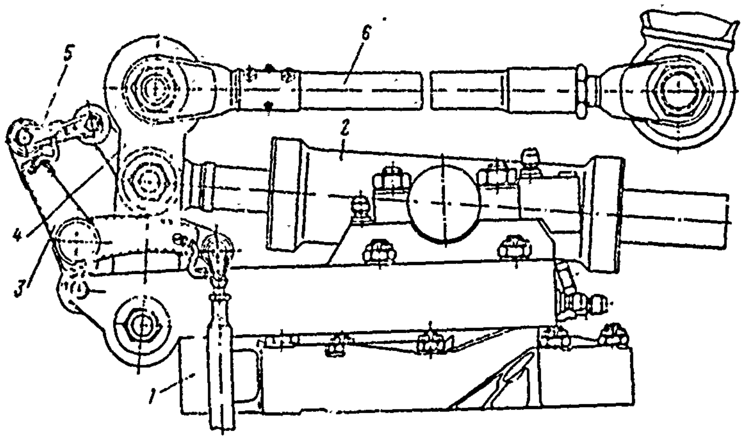

Fig. 94 Installation of the Longitudinal Control Hydraulic Actuator:

Key: 1) bracket, 2) hydraulic actuator, 3) rocker, 4) hydraulic actuator rocker, 5) link, 6) rod

For connecting the control rods running from the column to the rockers controlling the hydraulic actuator slide, rocker 3 connected by link 5 to the slide valve control rocker is installed on each hydraulic actuator body. Rockers 4 which are connected with the slave rods of the hydraulic actuators are connected by rods 6 to the rockers of longitudinal and lateral control of the rotor control assembly.

Control of the hydraulic actuators is accomplished in the following manner. When the control handle is moved, the system of rods and rockers is brought into motion. As a result of movement of the control lever, forces are transmitted to the hydraulic actuator slide valve control rocker. The fluid displaced by the slide valve brings the slave rod of the hydraulic actuator into motion and it rotates rocker 4 relative to the axis of its fastening, thereby moving rod 6 controlling the rotor control assembly. Rocking of the hydraulic actuator cylinder which takes place in this will take place relative to the axis of its trunions.

Directional Control

Fig. 95 shows the diagram of directional control for a heavy helicopter. It consists of pedals, a system of rods and rockers, a hydraulic actuator, multiplier, drum, cable linkage and a roller link chain.

The control linkage for the main rotor is of a mixed construction.

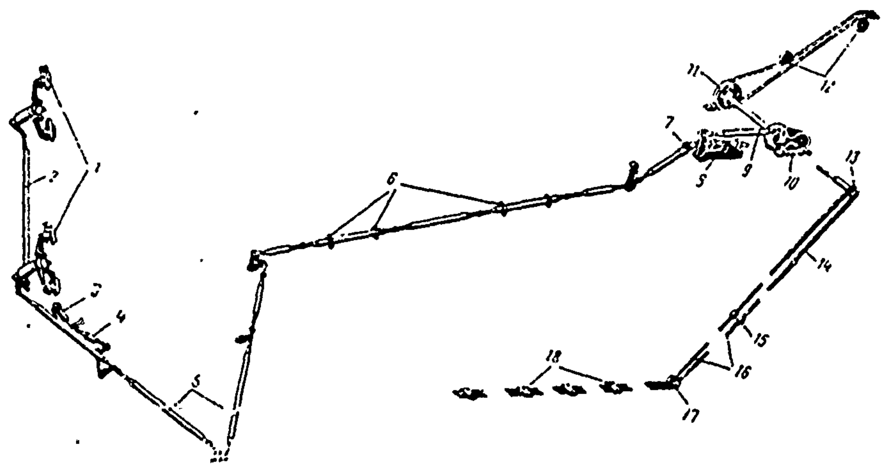

Fig. 95 Diagram of Directional Control:

Key: 1) pedals, 2) pedal connecting rod, 3) electric mechanism, 4) directional control loading spring mechanism, 5) directional control rod, 6) guide rollers, 7) rod with spring device, 8) directional control hydraulic actuator, 9) rod from hydraulic actuator to multiplier, 10) multiplier, 11) drum, 12) rollers, 13) star wheel, 14) roller link chain, 15) turnbuckles , 16) directional control cables, 17) rollers, 18) textolite guides

From pedals 1 to multiplier 10, the control linkage is of a rigid construction. The rods connect the directional control pedals with the hydraulic actuators through a system of rockers. Movement is transmitted to the multiplier from the hydraulic actuator.

The multiplier is intended to convert the relatively small travel of the rod from the hydraulic actuator into a large movement of the cable linkage. Such a system provides great control rigidity with a small diameter for the cable used. To increase control reliability, the cable linkage is doubled. The cables are terminated with a roller link chain 14 which passes around star wheel 13 of the tail reduction gear.

A change in the tail rotor pitch is accomplished by means of deflecting the pedals. When the pedals are deflected the hydraulic actuator is engaged and the multiplier lever is turned by rod 9. When this happens, the output shaft of the multiplier, which is connected with drum 11, rotates at an angle several times greater than the angle of multiplier lever rotation. When the drums turn, the cables, together with the chain, move and the tail reduction gear star wheel rotates. Rotation of the star wheel is converted into the progressive movement of the tail reduction gear rod by a spiral coupling. Movement of the rod is transmitted to the hub linkage, which rotates the bodies of the axial hinges, and a change in the rotor blade setting angle occurs.

The most widely used pedal construction is that of the parallelogram type (Fig. 96) which is made in the form of a separate component.

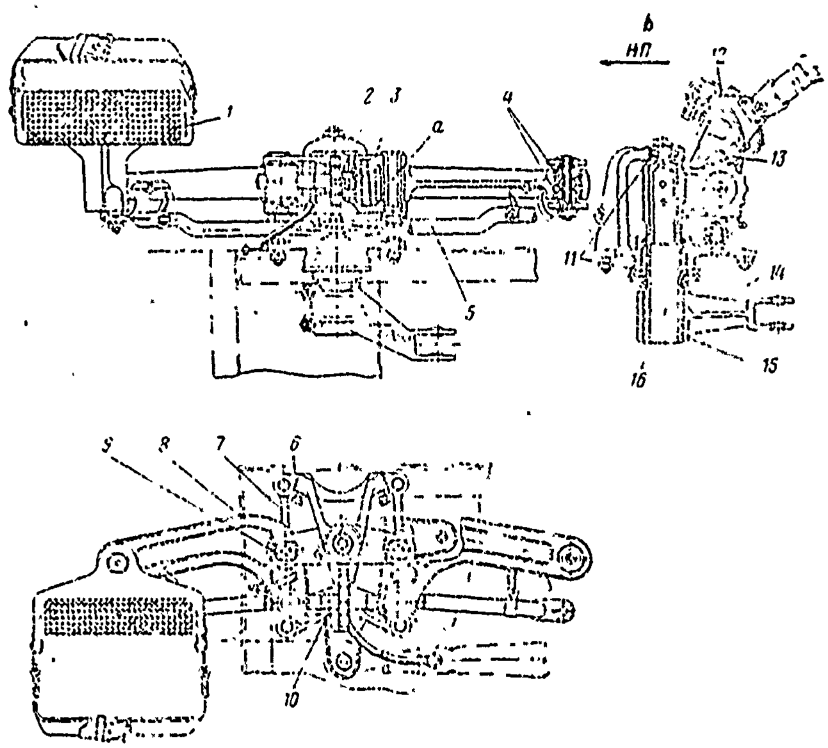

Fig. 96 Directional Control Pedals:

Key: 1) foot pedals, 2) bolt, 3) lever, 4) ball bearings, 5) rod, 6) adjusting bolt, 7) bracket, 8) lever, 9) bolt, 10) insert, 11) ball bearings, 12) support surface, 13) terminal switch, 14) rocker. 15) shaft, 16) adjusting screw with hand wheel, a) hole in bolt for fixing pedals in neutral position, b) direction of flight

Shaft 15 serves as the axis of pedal rotation. Two-armed lever 3 on which lever 8 is fastened in a hinge connection is fastened on the shaft. Pedal foot rest 1 is on a hinged connection on the large arm of the lever.

An insert with threaded holes for adjusting screw 16 and its hand wheel are installed on the small arm of the lever. By rotating the hand wheel of the adjusting screw, it is possible to adjust the pedals according to the height of the pilot.

Parallelness of pedal level is provided by two rods 5 which are joint fastened on the floor base and on the pedal foot rests.

Extreme deflection of the pedals is limited by adjustable bolts 6 which are installed on the pedal support.

Buttons with end switches for controlling the directional control loading spring mechanism are installed on the support surfaces of the pedals.

The hydraulic actuator and the multiplier are installed on a common beam (Fig. 97). The hydraulic actuator is set so as to be irreversible.

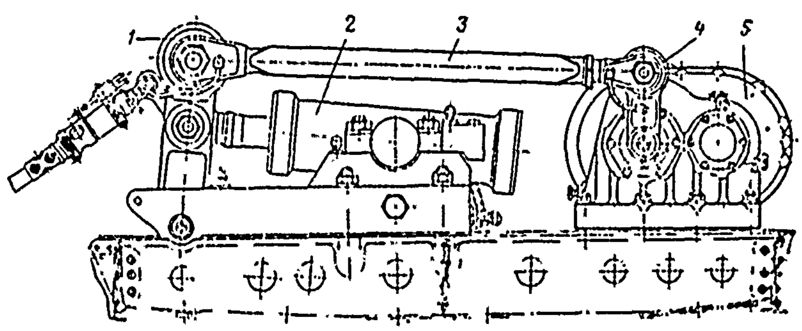

Fig. 97 Installation of Hydraulic Actuator and Multiplier:

Key: 1) hydraulic actuator rocker, 2) hydraulic actuator, 3) rod, 4) multiplier lever, 5) multiplier

The multiplier (Fig. 98) has two stages of gears.

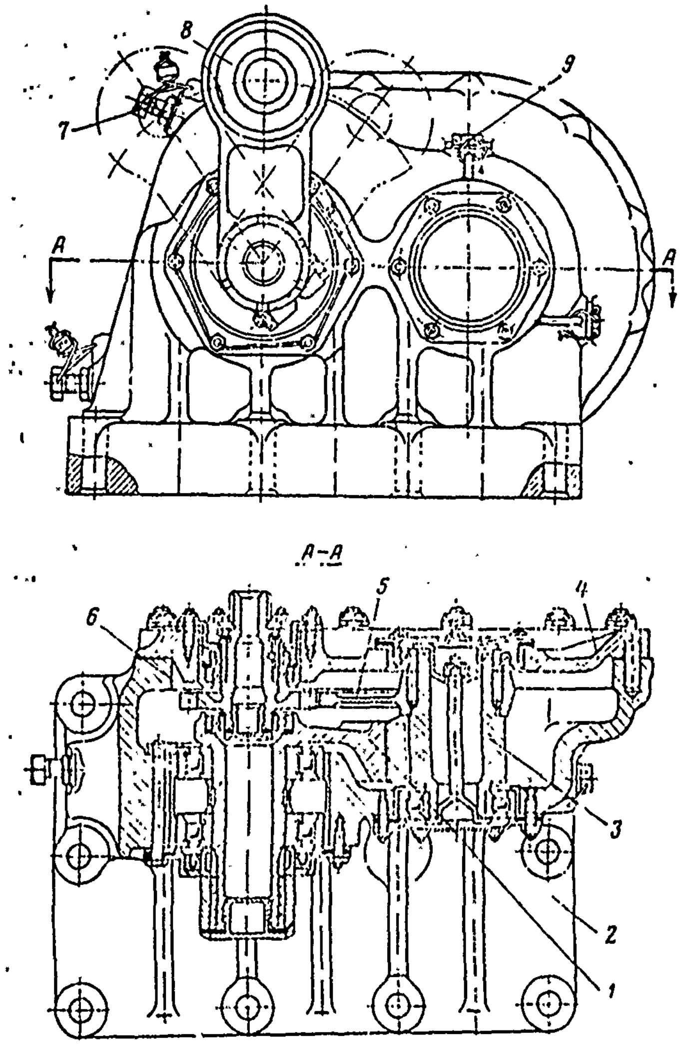

Fig. 98 Multiplier:

Key: 1) toothed sector, 2) housing, 3) toothed sector, 4) housing cover, 5) toothed sector, 6) toothed wheel, 7) limiting bolt, 8) lever, 9) plug,

The toothed sector and wheel are mounted on roller and ball bearings. Toothed sector 1 has an extended shaft, on the splines of which are installed lever 8 for connecting the rod from the hydraulic actuator.

The shaft of toothed wheel 6 emerges from the housing and is connected with the drum shaft by involute grooves.

Threaded holes with plugs 9 are provided in the housing. Oil level monitoring is performed through these holes and the oil is filled through them.

Spring Loading Mechanisms

The control system on helicopters is made according to a irreversible schematic. To create a positive gradient force on the control handle and pedals, and also to remove these forces when flight configurations are set in the system of longitudinal, lateral and directional control, spring control loading mechanisms (trimmers) are included in them.

Installation schematics for the loading mechanism with adjustable devices for the hand and foot controls are identical in principle.

Each such installation consists of a spring mechanism whose rod is connected with the control link of an electromechanism and an intermediate rocker, to which the body of the spring mechanism and the rod of the electromechanism are connected.

Control of the hand controls loading electromechanism is accomplished by pressing an 8-position switch which is mounted on the upper part of the control handle.

Control is accomplished by the switch either with the left hand or with the right one, for which a transfer switch on the instrument panel is set.

Control of the loading electromechanism for the foot control is accomplished by pressing on the triggers mounted on the pedal foot rests with the toes. The electric circuitry for engaging the electromechanism is made in such a way that if both triggers should happen to be pressed simultaneously, the electromechanism does not engage.

The essence of the adjustment according to changes in force on the lever consists of the fact that, with the electro mechanism, the spring loading mechanism moves along its axis, and consequently, the force characteristic is moved in one direction or the other relative to the neutral position of the control levers (pedals).

For loading mechanism position monitoring, indicators are mounted on the instrument panel. The sensors for these indicators are installed on the floor frame and their linkages are connected to the rods with the intermediate

rockers, which are inturn connected with the rod of the electromechanisms.

Construction of the spring mechanisms for loading the longitudinal and lateral control are identical (Fig. 99) and differ only in their dimensions and power characteristics.

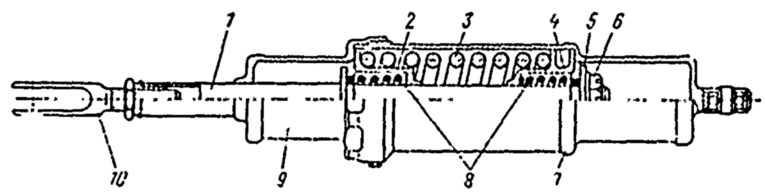

Fig. 99 Cyclic Pitch Control Loading Mechanism:

Key: 1) rod, 2) bushing, 3) main spring, 4) bushing, 5) flange, 6) nut, 7) cylinder, 8) small springs, 9) cover, 10) fork

The eye on cylinder 7 is intended for fastening the intermediate rocker which is connected to the electromechanism and the fork 10 is intended for connection to the cyclic pitch control link.

Main spring 3 and the two small spring 8, which are more rigid than the main spring, are installed with a preliminary compression so that the main spring is under relatively greater pressure than the small ones.

When rod 1 is moved relative to the cylinder in one direction or another, at first compression of one of the small springs takes place and the load is removed from the other until it is fully freed from its preliminary compression. When a compression force on the small spring is achieved so as to be equal to the force of the preliminary compression of the main spring, it begins to work together with the main spring until the rod collar or flange 5 stops against the bushing 2 or 4, after which only the main spring begins to work.

The springs are chosen in such a manner that an increase in the force gradient is created close to the neutral position of the control handle, as a result of which the sensing

of friction in the control handle is removed and the centering capability of the lever is improved. Characteristics of work of the longitudinal control loading mechanism are shown in Fig. 100.

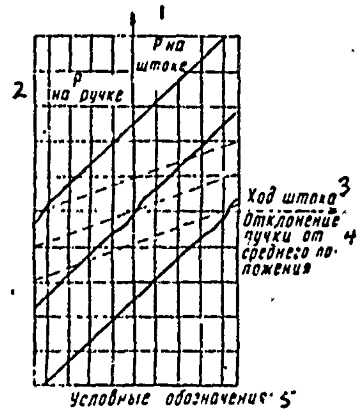

Fig. 100 Characteristics of Work of the Longitudinal Control Lever Loading Mechanism

Key: 1) P on the rod, 2) P on the lever, 3) rod travel, 4) deflection of lever from neutral position, 5) arbitrary designations, ——— mechanism characteristics, ----- force gradient on the lever

The directional control loading mechanism is made with one spring installed in the body with a small amount of preliminary compression for the purpose of simplifying construction.

The electromechanism consists of an electric motor, a planetary reduction gear, a roller spiral gear pair, limiting switch units and a small plug disconnector.

The electric motor in the mechanism is reversible. A braking sleeve is mounted on the electric motor for the purpose of braking the reduction gear when voltage feed is stopped.

The planetary reduction gear is used in the electromechanism to increase the torsion moment and decrease the number of revolutions transmitted to the spiral gear pair housing.

The roller spiral gear pair is intended to convert the rotational movement of the reduction gear output shaft into

the progressive motion of the nut-rod.

The limiting switch unit consists of two disengagers which are intended to break the electric motor circuit at the extreme positions of the rod.

Control of the cyclic control lever loading electromechanism is accomplished by pressing on the 8-position switch (Fig. 101).

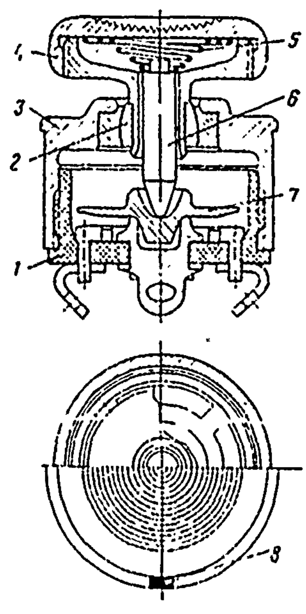

Fig. 101 Switch for Cyclic Control Lever Loading Mechanisms:

Key: 1) base with contacts, 2) ball hinge, 3) body, 4) handle with cap, 5) spring, 6) push rod, 7) contact disc, 8) red marking

The 8-position switch provides the possibility for engaging both electromechanisms and, consequently, also removing the loads from the levers in the following combinations.

1) Separate engagement of each mechanism provides removal of the loads from the levers in the longitudinal or lateral directions.

2) Simultaneous engagement of both electromechanisms gives the pilot the possibility of removing forces from the lever in the longitudinal and lateral directions with one switch.

The switch is designed for installation on the control handle in such a way that it can be engaged without removing the hand from the control handle.

The switch consists of a body with a handle, a base with contacts, a contact disc, springs and a push rod.

Handle 4 with its cap is fastened on ball hinge 2 in body 3. The handle can be deflected in all directions from the vertical position.

Internal threads for fastening base 1 with its contacts are formed in the lower part of the body. The cap, with which spring 5 of push rod 6 is compressed, is threaded onto the handle. Base 1 serves to fasten the contacts: one central and four located around the perimeter. The contacts have poles for soldering on wires on the outer side of the base.

A depression along which the push rod slides is formed in the center of disc 7. The disc is held on the central contact by its projection. Spring 5 is intended to press the push rod against the surface of the depression in the disc.

When the switch handle is pressed to the side, the push rod is deflected, sliding along the surface of the disc depression, passes outside the point supporting the disc in the neutral position and deflects the disc until it touches contacts located around the perimeter. The handle is returned into the neutral position by the spring. The resultant force of the spring, acting on the push rod, is always directed toward the center of the disc.

Combination of Controls for the Main Rotor Collective Pitch and the Engines

Control of the main rotor collective pitch and the engines on a helicopter is accomplished with the common "pitch-gas" lever 1 (Fig. 102), which is kinematically connected to the slide of the rotor control mechanism and is simultaneously connected to the levers of the fuel pumps located on the engines.

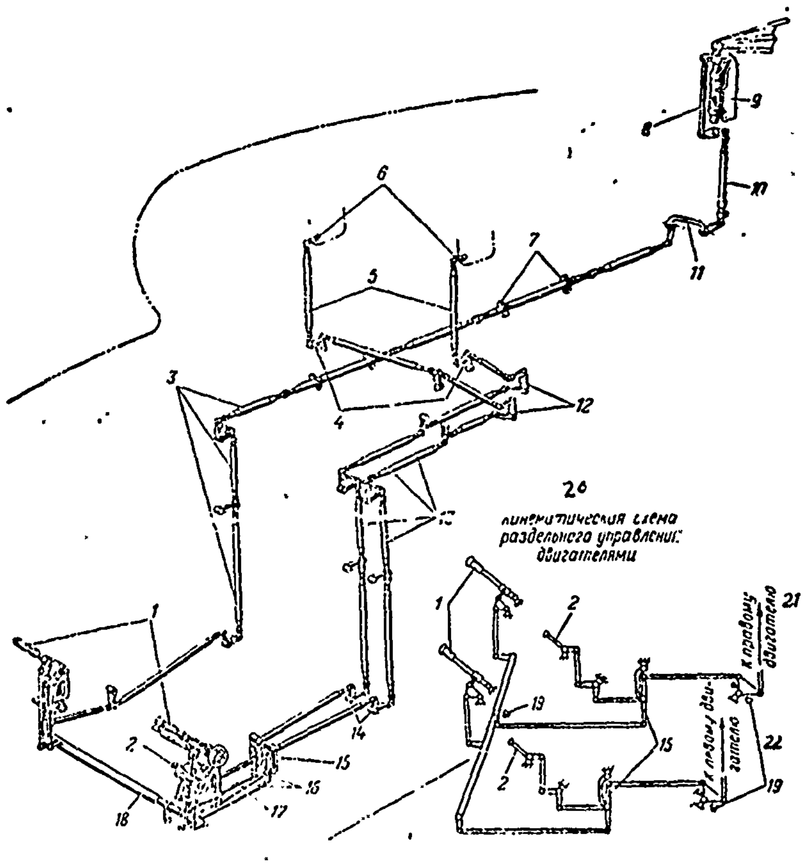

Fig. 102 Diagram of "pitch-gas" Combined Control:

Key: 1) "pitch-gas" combined control lever, 2) lever for separate engine control, 3) collective pitch control rods, 4) rockers, 5) engine control rods, 6) engine pump control levers, 7) roller guides, 8) rod, 9) collective pitch control hydraulic actuator, 10) rod with spring device, 11) rocker, 12) engine control rocker units, 13) engine control rods, 14) rockers withh adjustable supports, 15) differential unit, 16) engine control rods running from levers, 17) engine control rods, 18) connecting shaft, 19) adjustable supports, 20) kinematic diagram of separate engine control, 21) to right engine, 22) to left engine

When the "pitch-gas" lever is moved upward, main rotor collective pitch is increased and the engine power setting is simultaneously increased to a greater rate.

Separate controls for the engines allowing each engine to be tested separately without changing the collective pitch of the main rotor are provided in the helicopter along with the common control.

Separate control is realized with two levers 2 , which are installed on a common bracket of the "pitch-gas" lever by the left seat.

Combined control of the "pitch-gas" system consists of two handles 1, which are kinematically connected together with rods and a shaft, and are connected by the rigid link of the main rotor collective pitch control with hydraulic actuator 9, and are connected to the rigid link of the engine control and to levers for separate control of the engines. Rod 16 from the levers is engaged to the engine control linkage through differential unit 15.

Shaft 18 which connects both handles is located beneath the floor. From the handles, it is connected with four rods, two of which are for control of the collective pitch, two others being for control of the engines.

The "pitch-gas" system serves as a backup (emergency) system for adjusting main rotor revolutions, in that the main system for automatically maintaining the number of main rotor revolutions is on the engines. The pilot must transfer from the system for automatically maintaining the number of revolutions to the "pitch-gas" system and back by turning the correction handle.

With correction to the right, the system for automatically maintaining revolutions works. When the correction handle is turned to the left, the system for automatic adjustment is disengaged and the "pitch-gas" system is brought into play. The pilot determines the moment for switching according to a decrease in main rotor revolutions during an extremely small rotation of the correction handle to the left.

The automatic maintenance of the number of main rotor revoluations is provided by static revolution adjusters in the free turbines. Revolution synchronizers provide identical power outputs from the engines.

The "pitch-gas" levers are installed on the cockpit floor on the left side of each pilot's seat.

The left "pitch-gas" handle, which is mounted on a bracket together with the levers for separate engine control, is a separate unit (Fig. 103). On the upper part of the handle are buttons: "pitch-gas" lever friction disengager 31 and light control 32. Two more buttons are installed on the handle of a transport helicopter: tactical cargo release 29 and emergency release of cargo from external suspension 30. The buttons are mounted in body 8, the lower part of which is fastened to the body of the handle, and the upper part of which is fastened through a ball bearing hinge to the turning correction handle. This fastening provides the stationary position of the body and buttons when the correction handle is turned. The electric wires from the buttons pass inside body 8.

The "pitch-gas" handle is mounted on shaft 15, on which there is a disc friction device with electrc-hydraulic control.

The friction device holds the "pitch-gas" lever reliably in any position, providing the possibility for the smooth setting of the rotor control assembly, and, consequently, the main rotor collective pitch, in the required position. Normal friction is set with handwheel 21 so that, without pressing on friction device disengaging button 31, the "pitch-gas" lever can be moved with a force of 20 - 25 kg. If necessary, the friction device tensioncan be adjusted with handwheel 21. When the handwheel is turned, pressure bushing 20 moves and increases or decreases the preliminary force of compression on the spring, as well as pressure on the friction device itself. Friction is disengaged by pressing on button 31, which triggers an electromagnetic valve of the hydraulic system and liquid is forced through nozzle 14 into the cylinder for piston 17. Under pressure of the liquid, the piston moves, pressing away plate 16 and the friction disc is freed. When the finger is removed from the button, the slide of the electromagnetic valve moves, connecting the hollow in front of the piston with the drain, pressure in the hollow increases the and the plate again presses the friction disc under the action of the compression spring force.

Extreme positions of the handle are limited by stops 23, which are located on bracket 24, and by adjustable screws 22, which are installed in projections on the handle base.

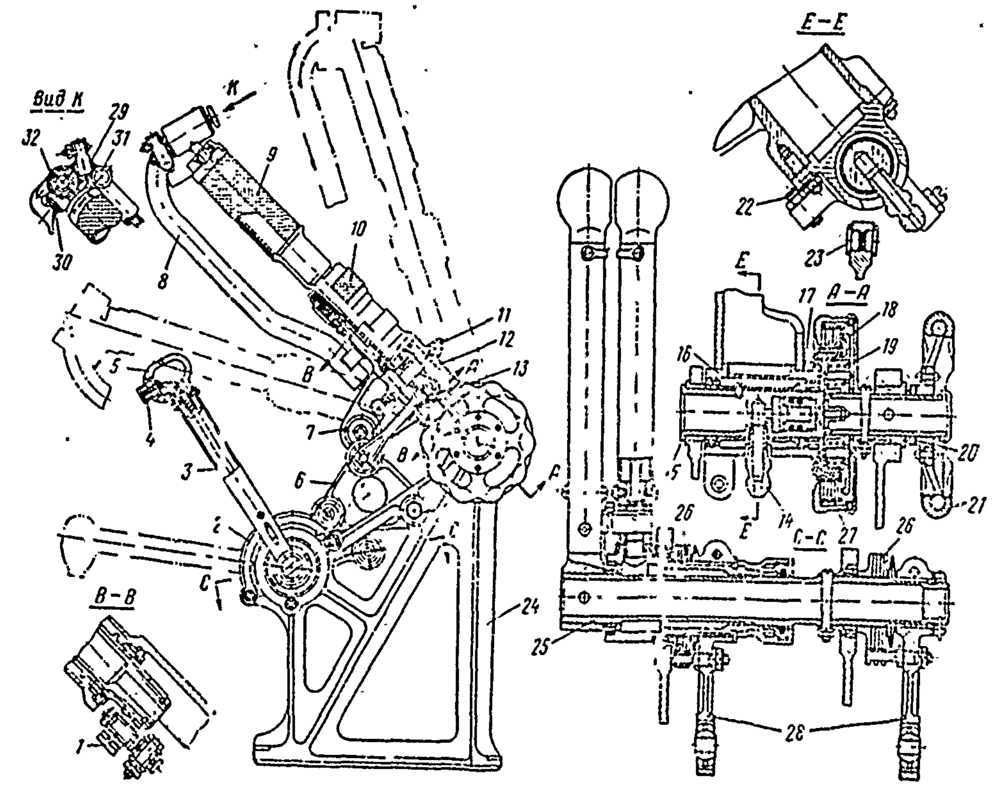

Fig. 103 Left "Pitch-Gas" Handle

Key: 1) linkage, 2) slide, 3) separate engine control lever, 4) catch lock button, 5) handle, 6) rocker, 7) body eye, 8) button fastening body, 9) rotating correction grip, 10) friction sleever, 11) limiting screw, 12) button body, 13) link, 14) nozzle, 15) shaft, 16) handle base, 17) piston, 18) plat., 19) supporting disc, 20) pressure bushing, 21) handwheel, 22) limiting screw, 23) stop, 24) bracket, 25) lever shaft, 26) lever friction mechanisms, 27) friction discs, 28) levers, 29) button for tactical cargo release from external suspension, 30) button for emergency cargo release from external suspension, 31) button for disengaging "pitch-gas" lever friction device, 32) light control button

Eye 7 on the body of the ball bearing is for connecting the handle. Rotating correction handle 9 with its tail is installed on two ball bearings in the handle body. Linkage 1 is fastened on splines on the end of the tail with a hinged eye, to which link 13 of the engine control system is connected.

When the "pitch-gas" lever is moved or the correction handle is turned, movement is transmitted to rocker 6 and then by a rod to the lever of the connecting shaft. The full angle of rotation of the correction handle is 90° and is limited by two screws 11 which are screwed into the handle body. The rotating handle has a disc friction mechanism whose degree of compression is adjusted by sleeve 10.

The two separate engine control levers 3 are installed on a common shaft. One lever is rigidly fastened on shaft 25, and the second, having a bushing, is installed on the same shaft on two ball bearings. Levers 28 are installed on the bushing and on shafts 25, and the separate engine controls are connected to the levers. Both levers 3 have friction devices 26, and it is therefore necessary to apply a force of about 3 - 4 kg to move the levers. The friction device consists of a movable and stationary disc and plate springs which press the discs.

Each lever 3 is fixed by a tooth in a detent in slide 2. The lever is freed from the catch lock by pressing on button 4. Movement of the lever upward from the neutral position provides transfer of the engine to a greater power setting and movement of the lever downward changes the engine to a lower power setting.

The right "pitch-gas" lever, differing from the left one, does not have a friction device, separate engine control levers or buttons for tactical and emergency cargo release from external suspension.

Stabilizer Control

Changing the angle of stabilizer setting on a helicopter is connected with the helicopter's trim. When the collective pitch is changed, the trim of the helicopter is disturbed. The helicopter can be trimmed in its new configuration with the stabilizer.

Construction of the stabilizer control linkage is mixed (Fig. 104). Motion from the slide of the rotor control assembly is transmitted by rigid rods to a sector, and from the sector by cables to the drum of a screw mechanism.

Movement of the screw mechanism is transmitted to the stabilizer. The control unit is connected to the slide of the rotor control assembly.

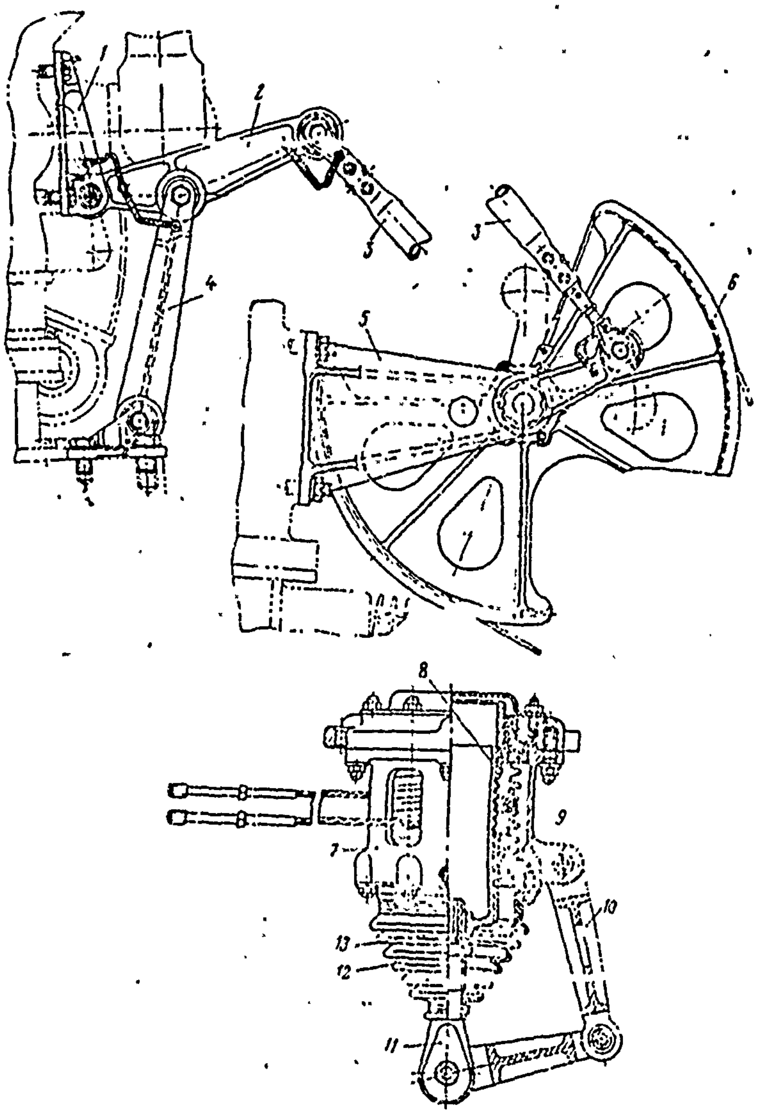

Fig. 104 Stabilizer Control Units:
Key: 1) bracket, 2) rocker, 3) rod connected to sector lever, 4) connecting rod, 5) bracket, 6) sector, 7) screw mechanism body, 8) screw, 9) drum, 10) spline hinge, 11) fork, 12) b[illegible], 13) key

The sector is installed on a bracket which is fastened on the body of the main reduction gear. The ends of the cables formed into connecting tips, are fastened on to the sector by bolts. Cables from the sector to the screw mechanism are laid along the tail portion of the fuselage and tail boom.

Construction of the screw mechanism is that of a spiral pair. There are channels for the cable on the outside surface of the nut. Inside the nut on trapazoidal threads is threaded a screw which moves rotation of the nut along its shaft. The screw is prevented from turning by a spline hinge.

Control of the Transmission Brake

Control of the transmission brake is accomplished by a handle which is connected by cables to the brake lever.

Control of the brake is interlocked with the engine starging system, as a result of which starting is possible only when the transmission brake is fully freed.

The brake control handle (Fig. 105) is installed in the pilot's cockpit on the right side of the left seat and is mounted on bracket 11 with toothed sector 10, which is intended for locking the handle in various positions. The handle is locked with catch 4 which is pushed into detents in the sector by spring 5. The handle is unlocked by pressing on button 1 which is connected by rod 2 with the slide, in which catch 4 is installed. Shaft 6 of the handle is installed in a bracket on ball bearings which are protected from dirt by felt seals.

The cable goes to the brake lever from lever 7 which is fastened on the shaft.

The brake control is interlocked with the engine starting system by limiting switches 8, which close the electric circuit of the engine starting system when the handle is in the lowered position. Triggering of the limiting switches is adjusted with bolts 9.

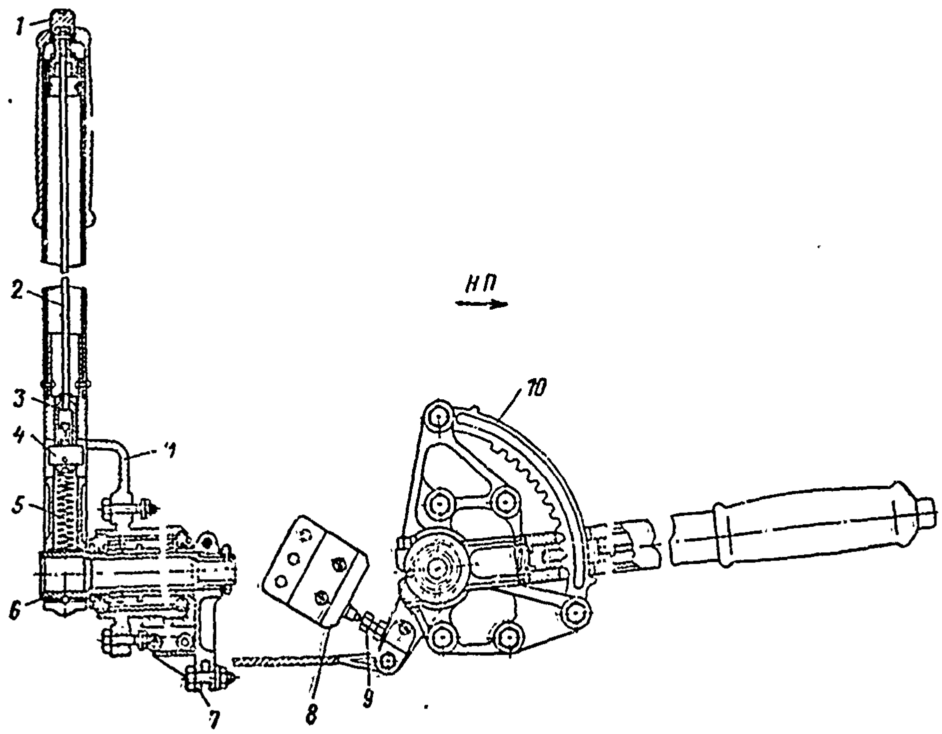

Fig. 105 Transmission Brake Control Handle:

Key: 1) button, 2) rod, 3) slide, 4) catch, 5) spring, 6) handle shaft, 7) lever, 8) limiting switch, 9) push rod-bolt, 10) toothed sector, 11) bracket

The Rotor Control Assembly

The rotor control assembly is a mechanism which allows the size and direction of the resultant aerodynamic forces of the main rotor (rotor thrust) to be changed through corresponding changes in the angles of blade setting.

A change in the resultant force in size is accomplished by simultaneously increasing or decreasing the angles of setting of all blades by the same amount, which is to say by changing the "collective pitch" of the main rotor.

Direction of the resultant force is changed by means of inclining the plane of rotation of the rotor control assembly plate, which causes a cyclic change in the angles of setting of the blades (when the plane of rotation of the rotor control assembly plate is inclined, the angle of setting of each blade changes according to the sine law depending on its azimuthal position).

The rotor control assembly is installed on the main reduction gear.

The rotor control assembly guide, through which the reduction gear shaft passes, is fastened to the flange of the reduction gear. The slide, with the plate unit and rockers for longitudinal and lateral control fastened to it with a hinged connection, moves along the guide.

The plate is brought into movement by a linkage, whose warping link is fastened on a bracket which is installed on the main reduction gear. The end hinges of the plate are connected by rods to the blade turning levers.

Control of the rotor control assembly is accomplished with hydraulic actuators working on the collective pitch lever and the longitudinal and lateral control rockers.

The basic aparts and components of the rotor control assembly, (Fig. 106),(see insert between pp. 66-67) are: guiding slide 7, slide 68, slide bracket 69, universal joint inner race 47, universal joint outer race 37, plate 50, the lateral control rocker, the longitudinal control rocker and linkage.

The guiding slide is a steel cylinder with a flange for fastening it to the main reduction gear. The sliding surfaces of the guide, along which the bronze bushings of the slide and the sealing rubber cups slide, are chromed.

Slide 68 is made in the form of a steel cylinder with bronze bushings 67 and 70, which slide along the guide, riveted inside it. The bronze bushings are riveted to the slide with rivets. Lubrication is forced into the hollow between the bushings. There is a flange on the inner portion of the slide to which slide bracket 69 is fastened on studs.

Two diametrically opposed holes are drilled into the upper part of the slide and radial ball bearings 6 of the plate universal joint are pressed into them. Universal joint outer race 47 is connected to the slide in a hinged manner by these bearings and to pins 54 and 55. The bearings are

lubricated through slide lubrication fittings together with lubrication of the bronze bushing. To protect the sliding surfaces from dirt and to hold lubrication in the slide hollow and in the ball bearings 66, two rubber cups 40 and 71 are installed in a special groove in the slide.

Universal joint inner race 47 is connected in a hinged manner by a second pair of pins 54 and radial bearings with universal joint outer race 37. The bearings are lubricated through lubrication fittings which are screwed into cover 53.

The common axis of the pins connecting the universal joint inner race with the slide is perpendicular to the common axis of the pins connecting the universal joint inner race with the outer one.

With this connection, the universal joint outer race, together with the rotor control assembly plate mounted on it, can be slanted in all directions relative to the slide. The plate of this rotor control assembly has the following angle of deflection parameters, which are limited by stops on the rockers: $\pm 7^{\circ}30'$ in the longitudinal control plane and $\pm 5^{\circ}30'$ in the lateral control plane.

Two cantilever pins 55 are fastened on the universal joint outer race 37 at an angle of 90° from each other and the longitudinal and lateral control rods are fastened to them through ball bearings. The bearings are covered with boots 11. Lubrication fittings are screwed in to lubricate the bearings and pins 55. The pins are placed in such a manner that the points for connecting the longitudinal and lateral control rods to the universal joint outer race are displaced from the longitudinal and lateral axes of the helicopter by 21° opposite the direction of rotation. With these placements of the points, the independence of longitudinal and lateral control is ensured.

Rotor control assembly plate 50 is installed on the cylindrical surface in the upper part of the universal joint outer race on a radial-supporting two-row bearing 30. The nose of the bearing is clamped down by nut 36, which is fixed with a lock. The outer race of the bearing is pressed by flange 32 against the butting collar of the bushing 31, which is pressed into the plate.

Plate 50 is manufactured by the stamping method out of aluminum alloy in the form of a 5-point star with a massive central ring. Steel cups 23 for assembling the end hinges of the plate are pressed into the arms of the star, which

are located at an angle of 72° from each other. Reinforced rubber cups 29 and 33 which seal the hollow of bearing 30 are located in flange 32 and in the body. The working surface of upper cup 33 slides along the cylindrical surface of ring 34, and the working surface of the lower cup slides along the cylindrical surface of universal joint outer race 37. The upper cup is protected from the entry of water and dirt by screen 35 which is screwed onto nut 36. Lubrication of bearing 30 takes place through lubrication fitting 27. Excess lubricant during lubrication is extracted through a limiting valve.

Hinged shafts 13 are installed in cups 23 on needle and radial bearings. The location of the shafts is accomplished with covers 17, along the cylindrical surface of which slide sealing rubber rings 16 which are placed in the slots of ring 15.

Hinged shafts are connected with pins through two radial bearings 12 and with the blade turning rods. Shaft bearings 13 and the pins are lubricated through lubrication fitting 22. Excess lubrication is drawn off through limiting valve which is located next to the lubrication fitting. The pin bearings have protective washers on one side.

The rotor control assembly plate is rotated by a linkage which is a kinematic chain consisting of the following basic parts: bracket 38, warping link 49 and lever 58 which are connected together with a moving joint. Rotation of the plate in any of its directions and progressive movement of it along the guide is provided due to this kinematic chain.

Linkage bracket 38 is mounted on the body of the main rotor hub and fixed in a definite angular position by stud 45. Warping link 49 is fastened to this bracket by pin 44 and two radial ball bearings. The inner races of the bearings are tightened by nut 41 and the outer races are pressed against the spring rings of the warping link by pin 42 through cover 43. Connection of warping link 49 to lever 58 is accomplished in a similar manner. The ball bearings are lubricated by filling the hollows of the bearings when the covers are removed.

Fork 61 is mounted on radial and needle bearings in a cylindrical hole in lever 58. The cylindrical surface of the fork is sealed with a rubber ring which is installed in grooves of nut 62, which presses the outer races of the bearing. The bearings are lubricated through lubrication fitting 56 which is screwed into lever 58. Pin 63 connects

fork 61 to shaft 65 through needle bearing 64. Body 60 is mounted on the shaft on two radial-supporting ball bearings. The inner races of the bearings are clamped by nut 59. The outer races of the bearings are clamped by butting body 60 with the horn of plate 50. The bearings of shaft 65 are lubricated in the same way as are those of shaft 13, through lubrication fitting 22.

The blade turning rod consists of bar 25, upper fork 26 and lower fork 14. On the inner hollow of the lower fork is the axial hinge of the rod in the form of a two-row radial supporting bearing, the outer race of which is clamped by nut 20, its inner race being clamped by nut 18. Boot 21 is fitted on the hinge to protect it from dirt and keep the lubricant in it.

The axial hinge allows the upper fork to rotate relative to the lower one. Upper fork 26 is screwed on to the threaded end of rod bar 25 and as a slot allowing the fork to be locked by tension bolt ? This construction provides the possibility of changing the length of the rod if necessary.

The plate of the rotor control assembly is inclined with fork 1 of the longitudinal control rocker and fork 10 of the lateral control rocker which are mounted on bracket 69. The bracket, stamped out of aluminum alloy, is fastened by pins on the flange of the slide. Steel bushings 4 and 80 are pressed into the bracket. The lateral control rocker is mounted on shaft 81 on tapered bearings. This whole assembly is clamped by nut 82. The longitudinal control rocker consists of shaft 3, on one end of which is fastened rocker lever 6 with external splines and screw 5, and on the other end of which is installed rocker fork 1 on the volute splines, compressed by nut 75. Bushing 4 is additionally fastened in the bracket by a pin and shaft 3 is mounted in it on needle bearings.

Axial placement of the longitudinal control rocker is accomplished through a washer which is held in position with a nut. Lubrication of the unit is accomplished through a lubrication fitting which is screwed into the bracket. There is a recess in the longitudinal control rocker arm for assembling a ball bearing. With this bearing and pin 8, the rocker is connected to longitudinal control rod 9, and rocker fork 1 is connected to the rod running from the hydraulic actuator. The ball bearing is covered with a rubber boot and lubricated through a lubrication fitting which is screwed into pin 8.

Scale 74 is fastened on bushing 4 with two screws and scale 2 is mounted on shaft 3 on splines and held together with rocker fork 1 by nut 75. There is a tooth on the scale disc, which, resting in projection of bushing 4, limits rotation of the rocker and subsequent deflection of the plate in the longitudinal control plane.

Lateral control rocker scale 76 is connected to disc 77 which is fixed at a definite angular position relative to bracket 69 by pin 79. The disc has a slot which limits rotation of the lateral control rocker. Rocker rotation is limited by pin 78, which fits into the slot of disc 77. Scale divisions are marked immediately on the lateral control rocker. The rocker scales allow deflection of the plate in the longitudinal and lateral control planes to be monitored and provide the possibility of adjusting controls on the helicopter without using a protractor and preliminarily setting the helicopter in the position in which the main rotor axis is vertical.

The collective pitch lever 51, in the eyes of which are inserted single-row ball bearings, is connected to slide bracket 69 by means of pins 72. The pins are prevented from moving an axial direction by bolts 73.

In the middle of the collective pitch lever face there is a recess with taper bearings installed in it. The taper bearings are supports for the pins of link 83. The other end of the link is connected to bracket 85 by pins 84 which pass through its holes. Bracket 85 has a similar recess with tapered bearings. Bracket 85 is fastened on to the main reduction gear housing with bolts. On the other end of collective pitch lever 51 is an eye for connecting the collective pitch control rod.

In this manner, forces from the controls deflect the collective pitch lever relative to its center support and therefore move slide 68, and together with it, rods 52, which are connected to the axial hinges of the main rotor blades. By means of raising the slide, the collective pitch lever also prevents it from rotating when forces are applied to the longitudinal and lateral control rockers.

Hydraulic Actuators

Hydraulic actuators are used to decrease forces on the control handles and pedals in a helicopter.

Hydraulic actuators are installed in the longitudinal, lateral and directional control systems and in the main rotor collective pitch control.

Combination hydraulic actuators (Fig. 107) are used on helicopters, and can work at two rates:

a) From manual (foot) control accomplished by the pilot;

b) From combination control with the autopilot engaged according to a mixed (differential) schematic. The hydraulic actuator works simultaneously from hand (foot) control and from signals from the autopilot within a limited range.

Combination hydraulic actuators are supplied from the main and backup hydraulic systems.

The pumps of the main and backup systems are installed on linkages of the main reduction gear, which provides normal operation of the hydraulic systems in the case the engine fails and the helicopter transfers to the main rotor autorotation configuration.

In case the main system fails, feed of the hydraulic actuator automatically switches to the backup system.

The pilot, deflecting the control handle to one side or the other, moves the slide valve of the hydraulic actuator, and liquid flows into one of the power cylinder hollows and moves the slave rod. Simultaneously with this, liquid from the other hollow of the cylinder is forced into the drain main line.

With combined control, the hydraulic actuators work off signals from the autopilot or simultaneously from the autopilot and from manual control performed by the pilot.

Combination (mixed) control of a helicopter is engaged by means of simultaneously supplying a signal for engagement of the autopilot and to the electromagnetic valve.

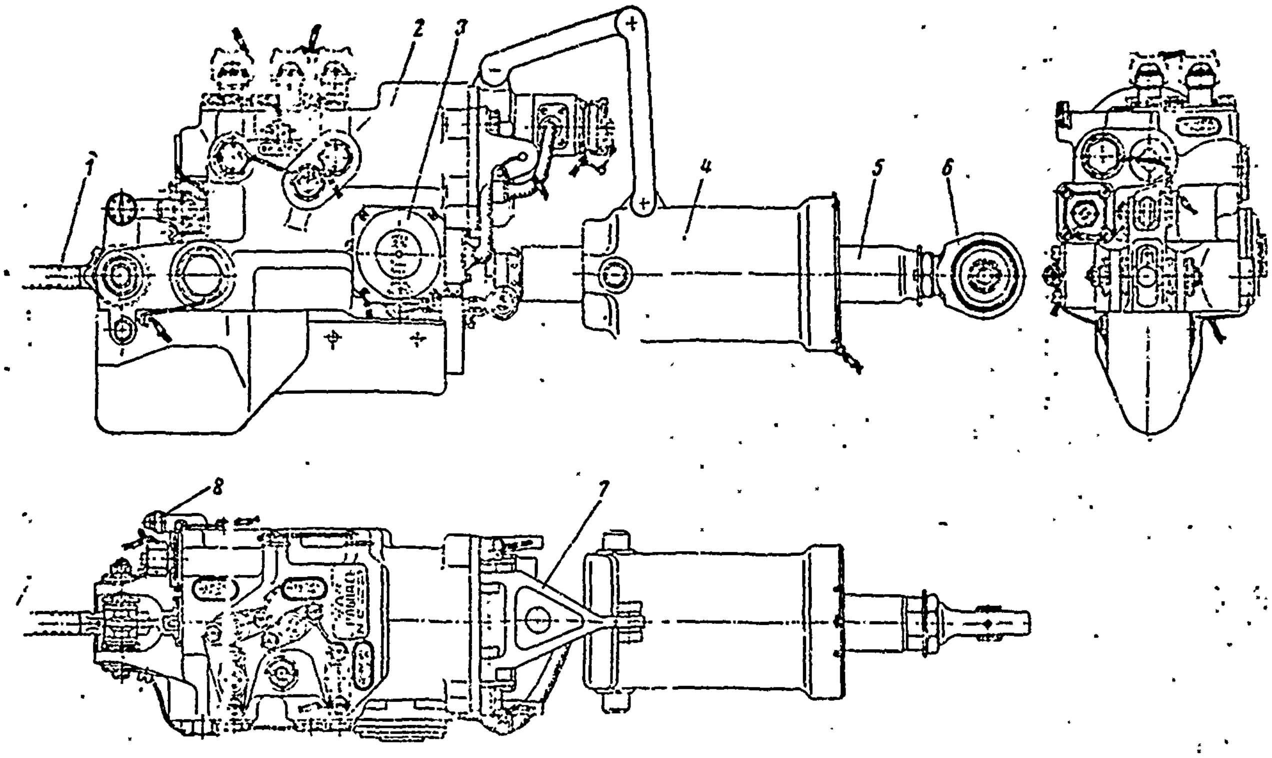

Fig. 107 Combination Hydraulic Actuator:

Key: 1) connector for fastening hand control rod, 2) distributor valve, 3) induction contactless potentiometer, 4) power cylinder, 5) piston with slave rod, 6) connector for fastening rotor control assembly control rocker, 7) split hinge, 8) angle fitting for connecting pipeline carrying liquid during engagement of the hydraulic actuator in the combined control mode

During combined control, actions of the pilot are transmitted through the control handle to the hydraulic actuator with simultaneous correction due to corresponding electric signals from the autopilot which provide automatic control of self-incited deflectins of the helicopter.

Disengaging the combined mode of hydraulic actuator operations in all control system is accomplished by means of

disengaging the autopilot.

In addition to this, disconnecting the altitude channel of the autopilot and the combined control mode in the collective pitch hydraulic actuator is accomplished by pressing the button for unlocking the "pitch-gas" handle friction device, which is to say when the pilot intends to change the flight altitude manually.

In the absence of pressure in the main and backup hydraulic systems, the pilot can control the helicopter manually, inclining and moving the rotor control assembly.

Design of Control Linkage Elements

The control linkage consists of the following elements: rods, levers, rockers, guides, cables, sectors and rollers.

The rods are usually made of duralumin tubes. The ends of the duralumin tubes are pressed to a single diameter for the purpose of decreasing the weight of the steel connecting fittings and their joints. The connecting tips are riveted into the ends of the compressed tubes with tubular rivets.

Hinge connections of the rods with the rockers are made on radial spherical ball bearings of the closed type. All bolts connecting the rods and rockers are manufactured to second class precision.

Two types of tube ends are used: adjustable and non-adjustable. Adjustable ends are cups having holes with threads for screwing in an eye or fork bolt. In this way, there is the possibility of adjusting the length of the rod during assembly of the control linkage. There are holes on the adjustable ends of the rods to monitor thread reserve.

The adjustable connectors are locked relative to the rod by means of clamping them with a lock nut.

To eliminate catching in the hinged connections between the rods and rockers during their assembly, and also during deformation of the helicopter body when it is loaded in flight, a clearance is provided between the eye and the fork, and a self-orienting ball bearing of the closed type is installed in the eye of the rod connector.

In this way, the rod can deflect relative to the rockers ... 'ane perpendicular to the hinge. As the result of this deflection, a force acts on the rocker which is perpendicular to the plane of its rocking. The transfers force creates a flexion moment at the place where the rocker is fastened to the bracket. To absorb this moment, the rockers are installed in the brackets on two ball bearings at a definite distance from each other. One of the ball bearings is installed with its support in the rocker collar and is rolled in, and the other is "floating". A spacing bushing is installed between the bearings. Due to this ball bearing installation, axial loads of the rockers in the brackets are avoided.

With the command levers in the neutral position, the rods must be connected with levers and rockers at an angle of 90° to avoid differentiation of control.

The guides for the control rods consist of rings with rollers which support the rod, increasing its natural frequency of oscillation.

Cables are used for flexible linkage. Turnbuckles, eye rings and connecting tips are used as the connecting and adjusting elements.

Rollers and bushings are used as guides in cable linkage. Rollers are used in places where the direction of the cable is changed. The diameter of the rollers is selected depending on the diameter of the cable and the angle of grasp. To prevent the cables from falling away from the rollers in case they loosen, protector brackets are installed on the rollers.

Guide bushings consisting of textolite plates are used to support the cable instead of rollers in straight sections of cable linkage.

Control of a helicopter, with the exception of a small portion of the directional control, is accomplished with rigid rods.

The basic types of rods are shown in Fig. 108a. Rods in front of hydraulic actuators can have special spring installations with limiting switches. These rods are intended to switch power to the hydraulic actuators from the main hydraulic system to the backup one Hydraulic system switching with this installation will occur in a case where definite forces are applied to the control handle or pedals.

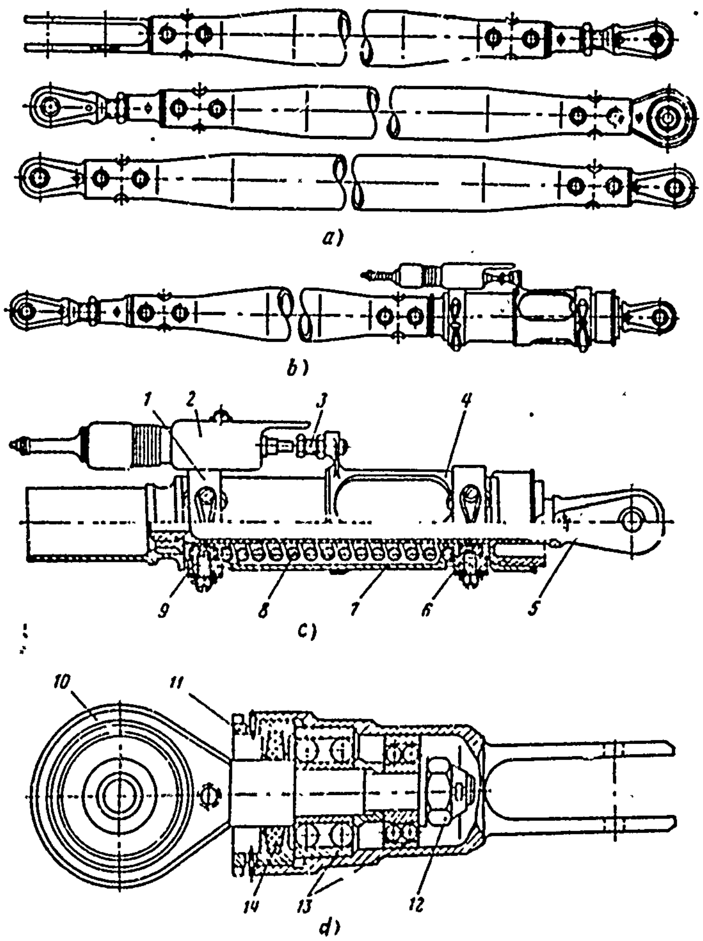

Fig. 108 Rigid Control Rods and Their Elements:

Key: a) basic rod types, b) rod with spring installation and limiting switch, c) spring connector and limiting switch, d) hinge link, 1) bracket, 2) limiting switch, 3) adjusting bolt, 4) bracket, 5) connecting tip, 6 and 9) stops, 7) body, 8) spring, 10) eye with tail piece, 11) nut, 12) nut, 13) ball bearing, 14) felt seal

An overall view of a rod with a spring installation and limiting switch is shown in Fig. 108b.

The construction of a control rod spring connecting tip is shown in Fig. 108c. Spring 8 is installed with a preliminary compression, the amount of which is set so that it is not deformed during normal operation of the hydraulic actuator.

The preliminary compression of the spring must be overcome if connecting tip 5 is moved and the limiting switchh 2 transfers supply of the hydraulic actuators from the main system to the backup one through the electric valve.

Movement of the connector is limited by stops 6 and 9 which are located in oval slots in body 7.

When a load extends the rod, the bushing with stops 9 moves, bracket 1 with the adjusting bolt 3 moves with it, and the adjusting bolt presses on the limiting switch push rod. Under a compressing load, the bushing with stops 6 moves and bracket 4 with a limiting switch fastened on it moves together with it.

The hinge link (see Fig. 108d) provides the possibility for free rotation of the lateral control rod which is located inside the control column shaft. This link consists of eye 10 with a tail piece and fork, mounted on two ball bearings 13 and clamped with nuts.

Construction of control rod guides and cable connections are shown in Fig. 109.

Roller guides consist of cast brackets 1, which are manufactured of magnesium alloy and rollers 2, which are pressed out of textolite meal. The axes of roller rotation are shafts 3.

Cable linkage is used on a helicopter for the directional controls.

To increase reliability, the cable linkage in the control is doubled. The cables are fitted into the connecting tips by pressing them.

Turnbuckles, consisting of bushings with right, and left, hand threads and connecting tips with corresponding threads are provided for adjustment of the controls and of

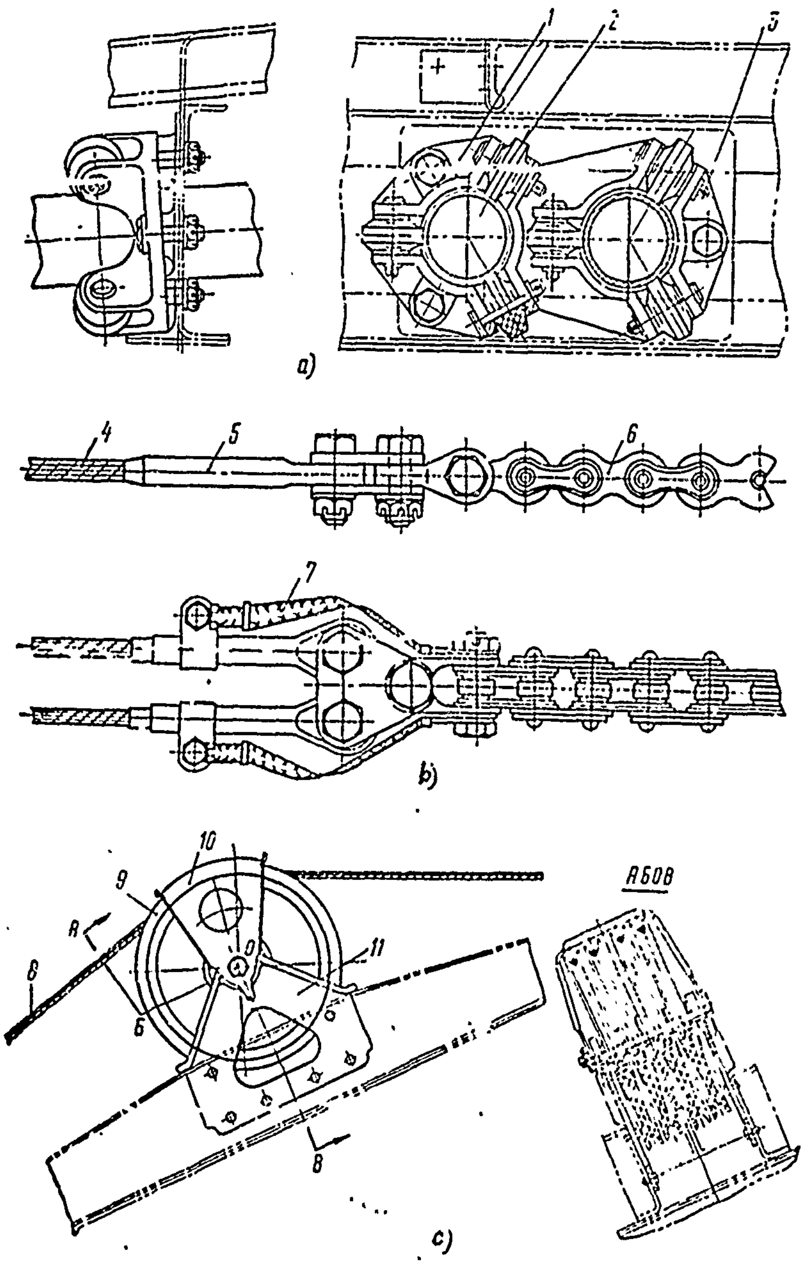

Fig. 109 Construction of Control Rod Guides and Cable Connections:

Key: a) rigid rod roller guides, b) connection of cables with a roller chain, c) cable linkage roller guides, 1) bracket, 2) textolite rollers, 3) shaft, 4), 8) cables, 5) connecting tip, 6) roller chain, 7) grounding strap, 9) roller, 10) limiter, 11) bracket

cable tension. The cable is riveted to the connecting tips. When the bushing is turned, the connecting tips are screwed inward or screwed outward, changing the length of the cable linkage.

The cable linkage in the directional control is terminated with a roller chain 6, which is connected to the ends of the cables by bolts through a special link.

The cable linkage is made with textolite rollers 9, into which ball bearings are pressed. Limiters 10 are installed to prevent the cables from falling out of their channels.

Control of the engines on a helicopter is realized with the separate control levers, deflection of the "pitch-gas" handle or rotation of the correction ring without deflecting the handle itself.

To provide independence of engine control from each of the enumerated systems, a differential unit (Fig. 110a) is installed in the engine control circuit. The differential unit consists of two pairs of rockers which are hinged together. Rocker 2 is fastened on bracket 4. If rocker 2 is locked by the separate control levers with rod 3, movement from the "pitch-gas" handle is transmitted through rod 6 and rocker 1 to rod 5 which runs to the engines. With this, rockers 1 rotate around the stationary axis of units 1 and 2. When the separate control levers are moved, motion from them is transmitted through rod 3, and rocker 2 is deflected relative to the shaft of part 4, and rocker 1 is deflected relative to shafts of units 1 and 6, which are stationary in this case, and the movement is transmitted to rod 5 which runs to the engines. As a result of the fact that the total movement from the "pitch-gas" lever and from the correction handle is greater than the travel of the engine levers, adjusting stops for extreme deflection are provided on rockers which are installed in front of the differential unit.

Special rockers (see Fig. 110b,c) are used to change the direction of force application in the control network.

The control rods must not fall into resonance under the effect of external vibrational loads.

It is advantageous to decrease the length of the control rods for the purpose of increasing their natural frequencies of oscillation.

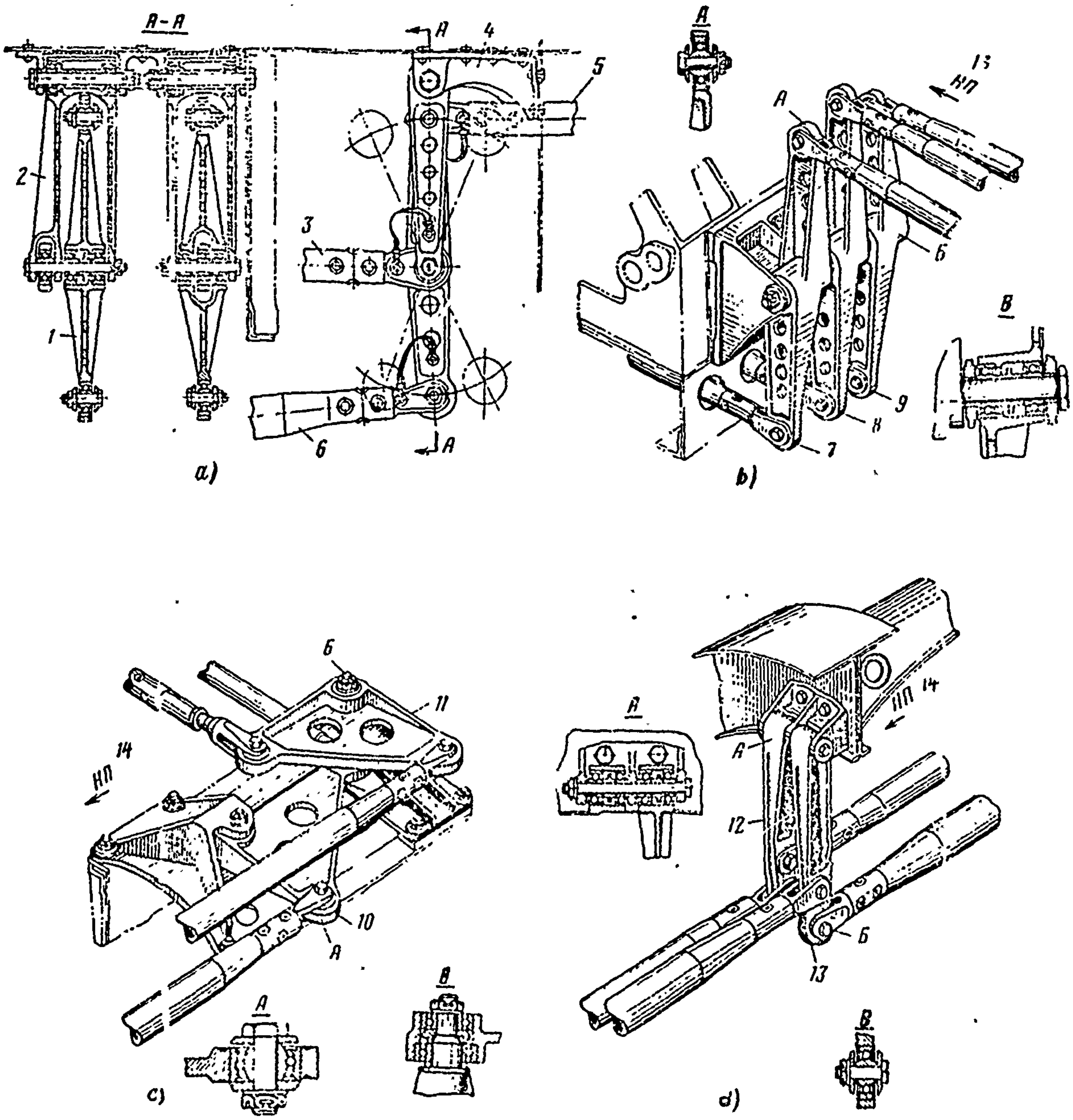

Fig. 110 Installation of Rockers and Rods Connected to Them: Key on following page

Key for Fig. 110: a) differential unit, b) rocker installation, c) manual control rocker installation in reduction gear compartment, d) typical installation of rockers in tail boom, 1 and 2) rockers, 3) rod from separate engine control levers, 4) bracket, 5) rod running to engine, 6) rod from "pitch-gas" lever, 7 and 13) directional control rockers, 8 and 10) lateral control rockers, 9 and 11) longitudinal control rockers, 12) stabilizer control rocker, 14) direction of flight

The control rods are loaded with forces of compression and tension, but they are calculated for total and local strength. To increase the allowable critical stresses of their overall strength, it is also advantageous to decrease the length of the rods.

Considering the given assembly, rockers are installed in the control circuit (see Fig. 110d) which do not change the direction of force applications in the control rods and do not affect the transmission ratio in the control system, but only support the rods.

To provide conditions for satisfactory radio reception during the flight of a helicopter, grounding is required for all movable connections which are insulated from each other by construction parts of the helicopter.

Grounding is accomplished with bridges made of copper plated braid. The connecting places for the bridges are cleaned down to bright metal and covered with lacquer after the bridges are connected. Some installations and brackets are grounded without the use of bridges. In these cases, grounding is provided by the immediate contact and is achieved by cleaning the surfaces of the touching installed parts and construction elements down to bright metal. Brackets made of steel and subjected to zinc or cadmium plating during the process of their machining are not subjected to cleaning during their installation without paint.

In a helicopter, the instrument panel, control rods and rockers, the cabin, the oil radiators, cables (at the turnbuckles), landing gear, fuel tanks, engine, oil tanks, handles controlling oil radiator plates and air intake louvers and the bracket fastening the pitot tube are grounded.

Section 8

Helicopter Landing Gear

Purpose of the Landing Gear and Requirements Outlined for It

The gear serves for parking and moving the helicopter along the ground while rolling before takeoff, rolling out after landing, taxiing and towing.

The gear absorbs loads acting on the helicopter during landing and movement along the ground. In accordance with this, the gear must have a device to absorb shock on the ground during landing. For this purpose, the helicopter gear, besides wheels, is fitted with shock absorbers.

The essence of shock absorption consists of the fact that the kinetic energy of the helicopter is expended on "deforming" the shock absorbing system (shock absorbers and tires) and the construction of the helicopter (gear, fuselage).

Work A^{o} (operational) expended by external forces on deforming the wheel tires and shock absorbers, is equal to the product of the external force P on the deformation of their total compression h, i.e. $A^{o} = Ph$. Therefore, the greater the amount of total compression of the shock absorber and tire, the less the force acting on the construction of the helicopter during one type of shock or another.

Shock absorption (the shock absorbers and tires) must absorb the operational work with a given overload and some reserve of travel (approximately 10% of full compression both in the shock absorber and in the tire).

Shock absorption must be soft with an increasing intensity of shock absorption, which is to say that the work must be absorbed with a small operational overload and the maximum force must be at the end of shock absorption travel.

The shock absorption must absorb possible oscillations from repeated shocks without allowing a sharp feedback to the reverse travel and without the wheels separating from the ground.

When standing, a helicopter usually has three points of support: two supporting points located symmetrically relative to the helicopter fuselage center line -- these are

the main legs of the gear, and the third supporting point located along the helicopter fuselage center line -- this is the tail or front (nose) leg of the gear. The main legs of the gear are located near the center of gravity of the helicopter, and its third support is located at a considerable distance from the center of gravity.

With the main legs of the gear located in front of the helicopter's center of gravity and the third support in its tail portion, the system carries the name -- tail wheel gear. If the wheels of the main legs are located behind the center of gravity, its third support (or two supports) are installed beneath the nose part of the helicopter, and the system bears the name -- nose wheel or tricycle gear. Tricycle gear is the main layout used in helicopters.

Out of the many types of shock absorbers, the most widely used are air-oil shock absorbers.

In single-rotor helicopters, a protective skid with shock absorption is installed on the tail boom for the purpose of protecting the reduction gear and tail rotor from striking the ground during the landing of a helicopter with an autorotating blade while it is flaring.

The wheels of the main gear legs are non-orienting and have brakes. The brakes here are less powerful than those in an airplane, since the helicopter is chiefly braked by the main rotor during landing rollout and directional control is used for turning the helicopter while taxiing.

The brakes on the main gear wheels serve to shorten the length of the helicopter's rollout after landing and during engine tests while stopped.

The nose (tail) wheel is made of the castor type. Parts for towing and tying down the helicopter are provided on the gear uprights.

Along with the general requirements for helicopter parts, (sufficient strength, low weight, simplicity of production and repair, convenience and reliability in operation, sufficiently high life of all gear construction elements, and also its mechanism and linkage) another group of special requirements are outlined for the gear:

1) Free, stable and controllable movement of the helicopter on the ground during takeoff run, rollout and taxiing;

2) Absorption of the energy of shocks both during landing of the helicopter and while it is moving on the ground. Besides this, gear shock absorption must have desirable characteristics of dampening "ground" resonance;

3) Minimal frontal resistance for gear which does not retract in flight;

4) Movement of the wheels relative to the longitudinal axis of the helicopter must be minimal during compression of the shock absorbers to avoid tearing off the casings;

5) Gear height must be such that with the tires and shock absorbers fully compressed, the remaining distance from the very lowest point of the fuselage and other components and parts to the ground surface is no less than 160 mm.

Design and Load-Bearing Diagrams of the Gear

Selection of the design and load-bearing diagrams of the gear is determined by the following considerations:

a) Operational requirements outlined for the planned helicopter;

b) Configuration of the helicopter;

c) Weight of the helicopter;

d) Aerodynamic requirements.

There are several layouts for gear: wheeled, skid, floating and others.

As a rule, tricycle wheeled gear are used on helicopters. This is explained by the fact that this layout has a number of essential advantages by comparison with tail wheel gear. These advantages include the following: safe and simpler landing of the helicopter in conditions of poor visibility and good directional stability during takeoff run and rollout.

The basic parameters of tricycle gear (Fig. 111):

1) distance from the nose wheel to the center of gravity of the helicopter -- a;

2) distance from the main gear leg wheels to the center of gravity of the helicopter -- b;

3) Wheelbase -- c;

4) Track -- B;

5) Tipping angle -- θ ;

6) Gear height -- h;

7) Antinose-over angle -- .

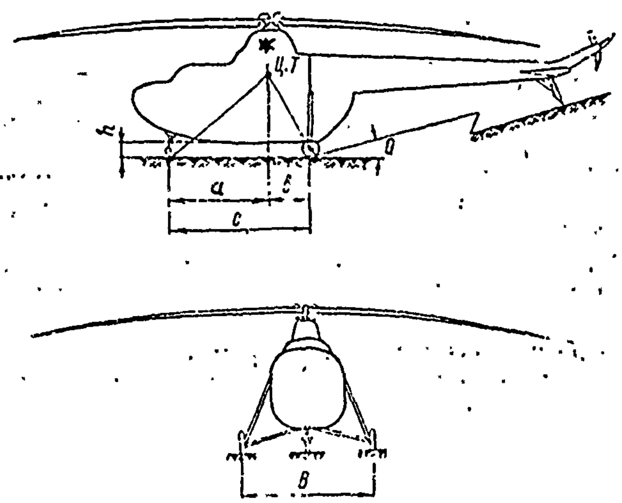

Fig. 111 Basic Parameters of Tricycle Gear

* center of gravity

The distance from the main gear wheels to the center of gravity of the helicopter is selected with consideration for the fact that these wheels must bear 85 - 90% of the weight of the helicopter.

If the wheelbase c is short, the helicopter will rock seriously in the longitudinal plane while taxiing.

If the wheelbase c is long (due to a) a very small load will be born by the nose leg of the gear and the rollout after landing will be unstable.

The minimum allowable gear track B is determined from considerations for the helicopter's lateral stability.

If the track is wide the helicopter will become sensitive to shocks in the main gear wheels due to an increase in the yawing moment.

The tipping angle θ is determined from considerations of safety while the helicopter is landing with an autorotating main rotor. The angle formed by a perpendicular dropped from the helicopter's center of gravity to a line connecting the points where the nose wheel and one of the main gear wheels touch the ground and by a vertical from the center of gravity is called the antinose-overangle γ. It is selected to be of a size so as to avoid the latrral tipping-over of the helicopter.

The question on the expediency of retracting the gear in flight is defined by comparing two values:

a) The required thrust for supporting the difference between the weight of retractable and fixed gear in flight;

b) The thrust required to overcome the aerodynamic drag of fixed gear for the cruise flight configuration.

If the thrust required to overcome the aerodynamic drag of fixed gear is greater than the thrust required to carry the additional weight of the gear retraction system, it is expedient to use retractable gear.

Besides wheeled gear, skid gear is used on helicopters (Fig. 112 a).

The skid gear is simple in production and has a lower weight than does wheeled gear. Wheels are used for movement along the ground on skids. The heels are installed on cranks so that when the crank is turned, the wheel is lowered beneath the skid, due to which the helicopter may be moved along the ground. Shock absorption in this gear is accomplished through bending of the tubes which fulfill the roles of springs.

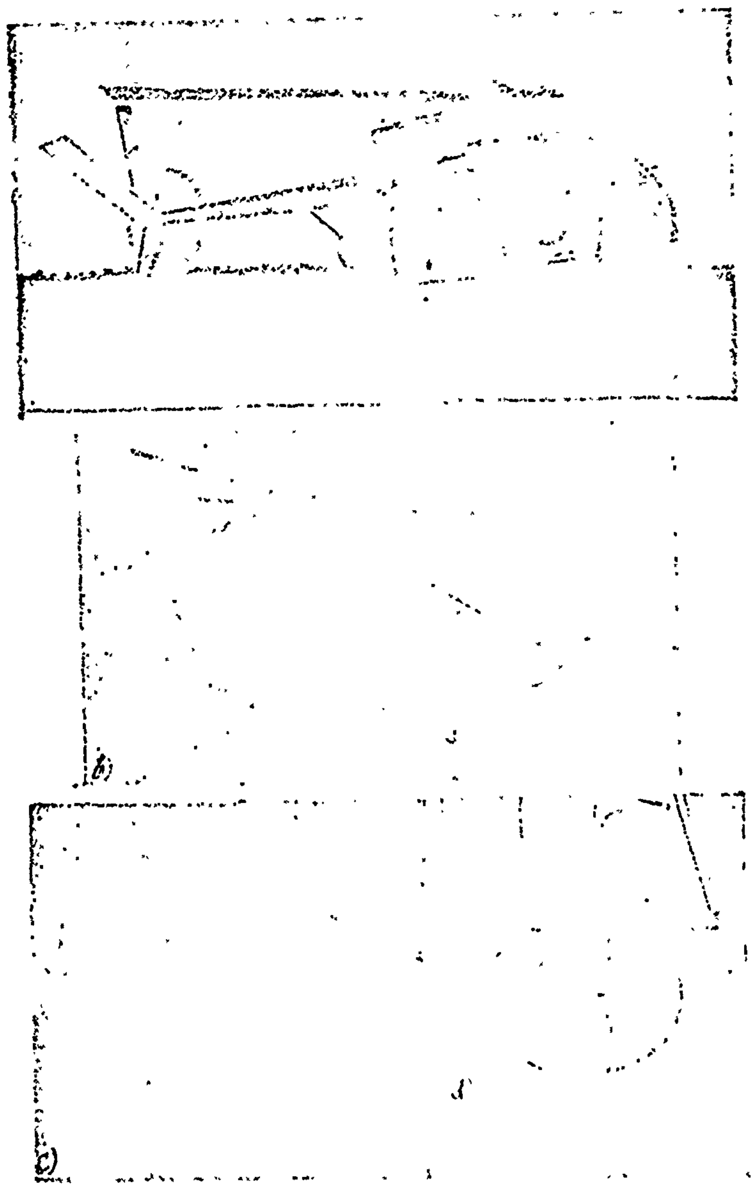

Fig. 112 Helicopter Landing Devices:

Key: a) helicopter with skid gear, b) amphibious helicopter. c) helicopter with floats. d) helicopter with balloons for emergency landing on water

For landing a helicopter on water and on dry ground, the lower portion of the helicopter fuselage is made in the form of a boat. Such a helicopter is called an amphibious helicopter (see Fig. 112 b). The form and section of the boat are selected out of considerations for minimum shock during landing on water, minimum splashing during movement on water and minimum resistance during takeoff run and breaking free from the surface of the water. To provide lateral stability, floats are installed along the sides of the fuselage. The boat and floats must be tight and have sealed compartments which are isolated from each other to provide flotability and stability if the bottom of the boat or floats is damaged.

For landing on the ground, wheeled gear with shock absorbing uprights are installed in the floats and a tail shock aborbing upright with a wheel is installed on the boat.

There are also amphibious helicopters with float balloons for landing on the water (see Fig. 112 c). The balloon floats create great hydraulic and aerodynamic drag and splash a lot during movement on the water.

Balloons which are filled with air at the moment they touch a water surface are used for the emergency landing of a helicopter on water (see Fig. 112 d).

Construction and Principles of Operation of Gear Shock Absorption

Shock absorbing struts and wheels serve as the shock absorbers on a helicopter and flexibly contract, absorbing the energy of the shock during contraction under the influence of external forces.

Liquid-gas shock absorption has received the most widespread usage. Gas (nitrogen) and liquid work simultaneously in this type of shock absorber.

When the shock absorber is compressed, liquid flows at a high velocity through calibrated holes, which creates hydraulic resistance. As the result of friction, part of the kinetic energy of the shock is transformed into heat. The nitrogen accumulates energy during the forward stroke of the shock absorber, providing the rebound stroke after the energy of the shock is absorbed by the shock absorber.

The work of a liquid-gas shock absorber is characterized by the following diagram (Fig. 113).

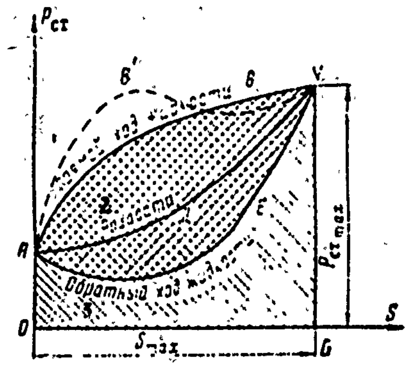

Fig. 113 Diagram of the Work of a Liquid-Gas Gear Oleo

Key: 1) forward stroke of liquid, 2) adiabat, 3) rebound stroke of liquid

Section OA determines the amount of preliminary axial force $P_{o\ ct}$, the so-called preliminary tension of the oleo. Due to it, the stroke of the oleo decreases and the coefficient of fulness of the oleo work diagram increases. The coefficient of fulness of the oleo work diagram is equal to the relationship of the area OABDGO, which is equal to the work absorbed by the oleo on the forward stroke to the area of a rectangle equal to $P_{ct\ max}\ S_{max}$.

A change in the liquid pressure during compression of the oleo (forward stroke) is characterized by the curve ABV. The area of the passage holes affects the character of this curve, and the holes are selected so that the area OABDGO corresponds to a given amount of work and the points on line ABV do not lie higher than its final point V like, for instance curve AB'V, which is to say so that the force in the oleo strut is maximum at the end of the piston's stroke.

The process of compressing the nitrogen is close to adiabatic, which is to say that it takes place without giving off heat.

The area OADVGO represents the work of external forces which are expended on compressing the nitrogen, and the area ABVEA defines the work of the oleo which is converted into heat, and characterizes the so-called hysteresis of the oleo.

The greater the hysteresis of the oleo, the faster the vertical oscillation of the helicopter during landing will be absorbed.

The area OAEVGO determines the work which is returned to the helicopter during the rebound stroke of the oleo.

Oleos in which the shock absorption materials are rubber in the form of cords or plates, and also steel in the form of leaf or coil springs, have a low hysteresis, and consequently, the energy of the compressed oleo which is not converted into heat will be almost totally fed back.

Fig. 114 shows the main gear leg of a heavy helicopter. The main gear legs of the pyramid type, located on both sides of the fuselage. Each main gear leg consists of half-shaft 1 with its wheel, rear strut 3 and two-chamber oleo strut 2.

Spring damper 4 with a pipeline and arch type wheel with a brake also go into the oleo system of the main gear legs. The gear half-shaft and rear strut are fastened by their upper ends to parts A and B, which are installed on the lower part of the fuselage. The half-shaft is connected with the fuselage part by means of a bolted hinge 7, the axis of which is located in a horizontal plane. The rear strut is fastened to the part on the fuselage by means of universal joint 5.

The oleo strut joins part C through an intermediate universal joint on its upper end and joins the half-shaft on its lower end.

The gear half-shaft (Fig. 115) has a flange 2 on its lower part which is intended for fastening the wheel brake, part 8 for fastening the strut, part 4 for fastening the oleo, eye 3 for a towing cable and a plate for jacking.

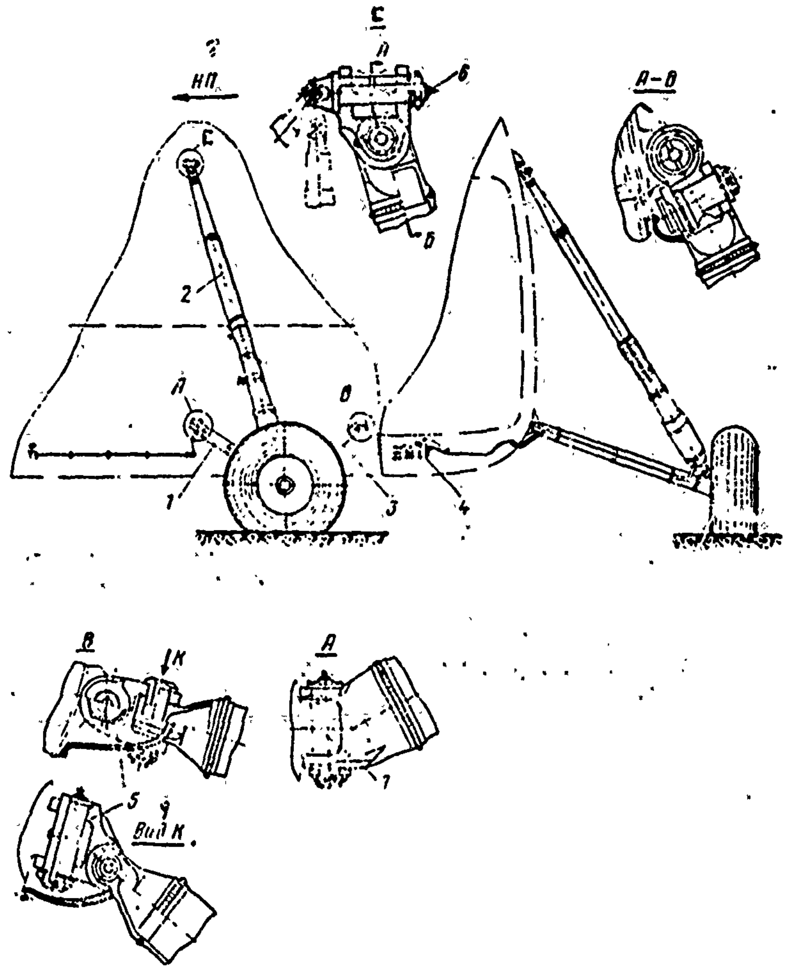

Fig. 114 Fastening of Main Gear Leg to the Fuselage:

Key: 1) half-shaft, 2) two-chamber oleo strut, 3) strut, 4) spring damper, 5) universal joint, 6) lubrication fitting, 7) bolt, 8) direction of flight, 9) view

A special yoke 5 for fastening the grounding pin is welded to the half-shaft. The wheel brake body disc is fastened to the half-shaft flange.

All joining bolts are manufactured to second class precision. There are fittings for lubrication in the bolts installed on the hinges.

The main gear legs are fitted with wheels having pneumatic shoe brakes. The wheel (Fig. 116), mounted on stub axle 22 on roller bearings 6, is retained by nut 3 which is locked with bolt 2. The roller bearings are fixed by spacing bushing 21 and are closed off by covers 1, which

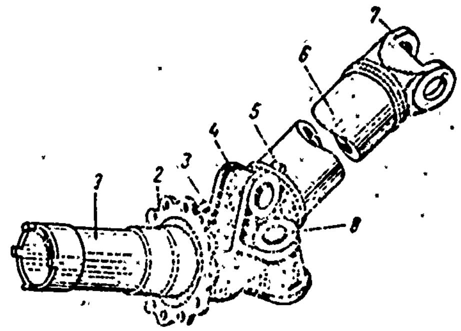

Fig. 115 Main Gear Leg Half-Shaft

Key: 1) stub axle, 2) flange, 3) eye for towing cable, 4) part for fastening two-chamber oleo, 5) grounding pin yoke, 6) pipe, 7) yoke, 8) part for fastening strut

have felt dust-protecting rings 4 on both sides of the wheel.

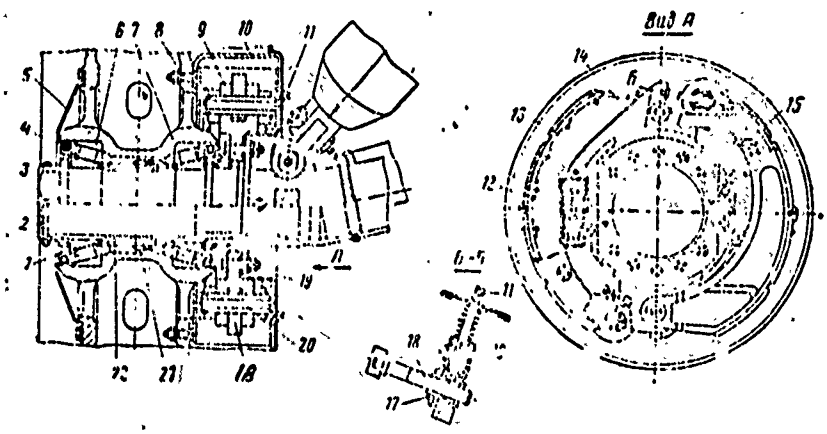

Fig. 116 Part for Fastening Main Gear Leg Wheel:

Key: 1) cover, 2) locking bolt, 3) wheel fastening nut, 4) dust-protecting felt ring, 5) wheel cover, 6) roller bearing, 7) wheel drum, 8) bolt fastening brake drum, 9) brake body, 10) brake drum, 11) adjustable rod, 12) brake air cylinder, 13) brake shoe, 14) lever, 15) return springs, 16, 17) bevel gears, 18) adjusting bolt, 19) bolt fastening brake body, 20) anchor pin, 21) spacing bushing, 22) stub axle

The brake drum is mounted in the wheel body on bolts 8 and brake body 9, the two shoes of which are installed on shafts 20, is fastened to the half-shaft flange by bolts 19. Clearances in the brakes are adjusted by rods 11.

Under the action of compressed air passing into the brake cylinders 12, the shoes are pressed against drum 10, creating braking of the wheels.

The two-chamber main gear leg oleo (Fig. 117) is intended to absorb the energy of the shock during landing and to dampen lateral oscillations.

The presence of the two low I and high II pressure chambers provide elimination of lateral oscillations which can arise during takeoff run or landing rollout of the helicopter, when the main rudder removes a significant part of the load from the gear. Besides this, the presence of the low pressure chamber makes the gear "softer" while the helicopter is being taxied.

The high pressure oleo is basically intended to absorb the energy of the shock during landing and has characteristics which are normal for airplane gear oleos. The main feature of a high pressure oleo consists of the fact that it does not work when the gear is under low loads, but stands on supports which correspond to the full travel of the strut.

The low pressure oleo is intended for work while the gear is under low loads.

On the lower part of the high pressure cylinder-strut 30 is an eye 33 for fastening the strut to the half-shaft part, drain fitting plug 32 and shaped needle 31 which screws into a recess and is locked with a lock nut.

At its upper part are mounted sealing rings 24 and sleeve 23 which are retained by nut 21, which has a dust-protecting ring 22.

Sleeve 28 with its longitudinal holes is screwed onto and "floating" valve 27 is installed in the upper portion of strut 19. Diffusor 29 with shaped needle 31 passing through its central hole is also mounted in the upper part of strut 19. Charging valve b is installed in the upper part of the strut hollow and bulkhead 18, covering the high pressure chamber, is welded inside it.

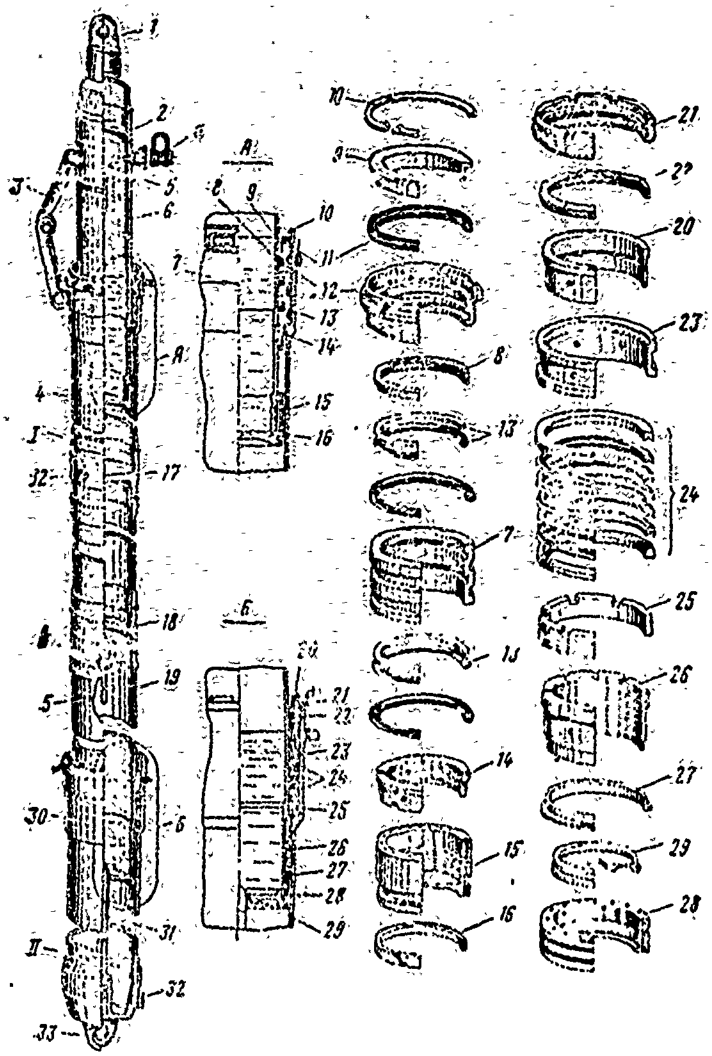

Fig. 117 Two-Chamber Liquid-Gas Oleo

Key: I) low pressure chamber, II) high pressure chamber, 1) eye for fastening oleo to fuselage part, 2) bulkhead, 3) slot hinge, 4) low pressure chamber cylinder-strut, 5) liquid filling limiting tube, 6) low pressure chamber strut, 7) low pressure chamber sleeve, 8) felt ring, 9) bushing, 10) expansion spring locking ring, 11) rubber buffer ring, 12) nut, 13) sealing rings, 14) nut, 15) low pressure chamber lower sleeve, 16) ring-valve, 17), 18) bulkheads, 19) high pressure chamber strut, 20) bushing, 21) nut, 22) felt ring, 23) high pressure chamber upper sleeve, 24) sealing rings, 25) nut, 26) spacing bushing, 27) ring-valve, 28) high pressure chamber lower sleeve, 29) diffusor, 30) high pressure cylinder-strut, 31) shaped needle, 32) drain fitting plug, 33) eye, a, b) charging valves

Sleeve 7, which is manufactured out of bronze, is mounted in the upper part of cylinder-strut 4.

The sleeve serves as a guide for the strut during its movement inside the cylinder. Rubber sealing rings 13 and spacing bushing 9 with rubber buffer ring 11 are installed in the sleeves.

Felt ring 8, intended for cleaning dust and dirt off the surface of the strut while the oleo is working is installed in an internal groove of nut 12.

Bulkhead 17 in strut-cylinder 4 covers the low pressure chamber. Sleeve 15 with its longitudinal holes and "floating" valve 16 are mounted in the upper part of low pressure chamber strut 6. The sleeve has a central calibrating hole for the passage of fluid. Charging valve a is installed in the upper part of the strut and bulkhead 2 is welded in it. On the upper end of the strut is eye 1 for fastening the oleo to the universal joint of the part on the fuselage cantilever.

To prevent the strut-cylinder 4 from rotating relative to low pressure strut 6, they are connected together by slot hinge 3.

The oleo is filled with AMG-10 oil. The oleo is filled through holes into which standard charging valves a and b are screwed. The oleo is charged with compressed technical nitrogen through these same valves. The initial pressure of the nitrogen in the low pressure chamber is significantly less than in the high pressure chamber.

When the helicopter lands, the low pressure oleo is compressed first. During this, strut 6, moving downward, forces the liquid out of the hollow of strut-cylinder 4 through the central calibrated hole in sleeve 15. The fluid simultaneously flows through the circular clearance between the sleeve and the internal surface of valve 16, which is pressed against the upper face of the sleeve groove, and also through the longitudinal holes in sleeve 15 into the circular space between the cylinder and the strut. During this, the quantity of liquid moved is regulated by a passage section of the longitudinal holes in the sleeve.

During the rebound stroke, valve 16 is pressed against the bottom face of the sleeve groove and the liquid flows through the longitudinal holes in the collar of the sleeve 15 into the cylinder. Since the summary passage section of the holes in the sleeve in the forward stroke is greater

than that for the rebound one, greater resistance to the flowing liquid is created during the rebound stroke. The liquid flows from the hollow of strut 6 into the chamber of strut-cylinder 4 through the central calibrated hole.

Work of the high pressure chamber is similar to that of the low pressure chamber. The difference consists of the fact that shaped needle 31 passes through the central calibrated hole in diffusor 29 and creates a changing passage section of the central calibrated hole in the diffusor according to the travel of strut 19.

The inner surface of the cylinder is ground. The working surfaces of the struts are polished and chromed.

A spring damper (Fig. 118) is installed on heavy helicopters to dampen lateral oscillations of the helicopter. Installation of the spring damper is such that it does not change the characteristics of the gear while landing on both main wheels simultaneously, but significantly reduces rigidity of the chassis during lateral oscillations of the helicopter.

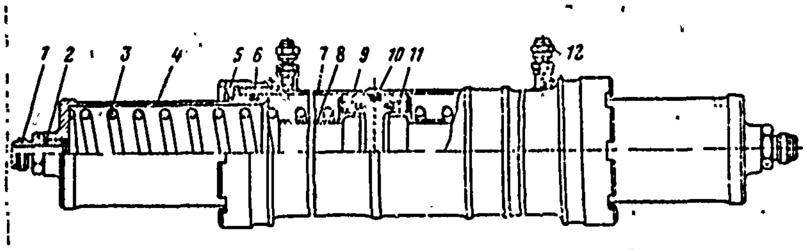

Fig. 118 Spring Damper:

Key: 1) nozzle, 2) sealing ring, 3) spring, 4) spring housing, 5) clamping nut, 6) sealing ring, 7) damper body, 8) piston tail piece, 9) piston, 10) sealing ring, 11) screw, 12) fitting with plug for bleeding air from system

The spring damper consists of body 7, two springs 3, piston 9, circular section rubber sealing rings and other parts.

A lever type oleo strut (Fig. 119) is used on the front gear, and consists of the following basic parts: cylinder 6, strut 11, plunger 7, turning bracket 15, connecting rod 21 and lever 22.

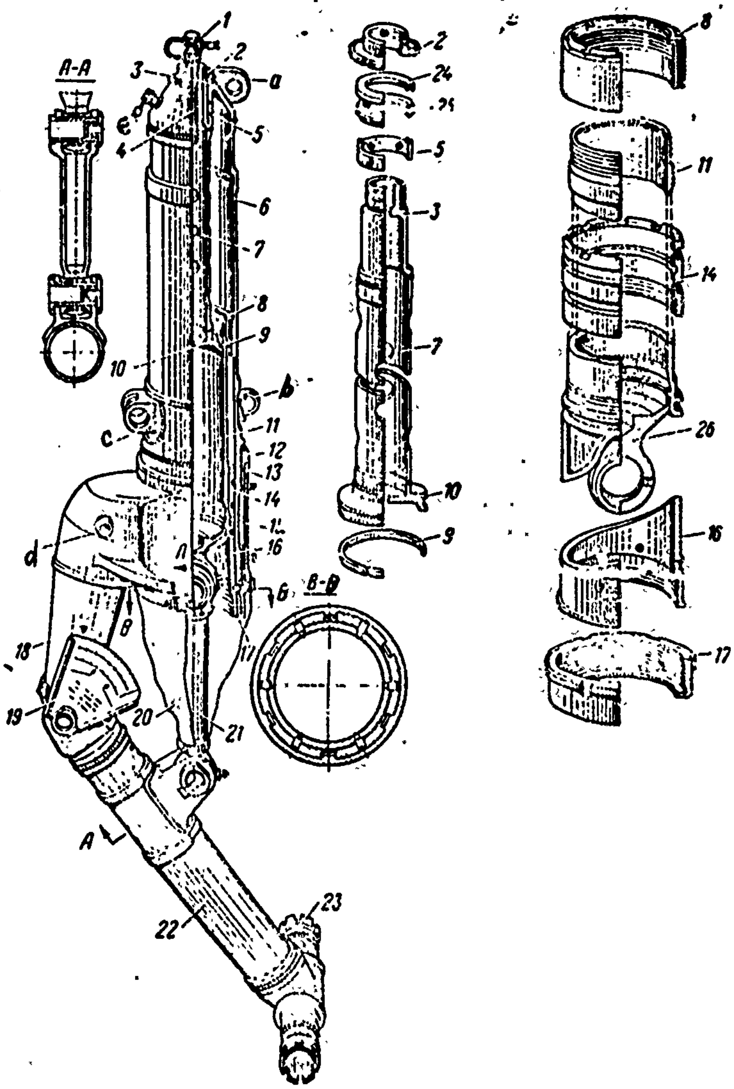

Fig. 119 Lever Type Oleo Strut

Key: 1) charging valve, 2) plunger fastening nut, 3) plunger tail piece, 4) charging tube, 5) locking plug, 6) cylinder, 7) plunger, 8) upper sleeve, 9) piston ring, 10) plunger piston, 11) rod with upper catch lock, 12) support ring, 13) bushing, 14) lower sleeve, 15) turning bracket, 16) lower catch lock, 17) nut, 18) turning bracket horn, 19) indicator for pressure in cylinder and amount of strut compression, 20) boot, 21) connecting rod, 22) lever, 23) wheel fastening nut, 24 and 25) sealing rings, 26) strut end. Key continued on following page.

Key for Fig. 119 continued from previous page.

a) upper eyes for fastening strut, b) lower eyes for fastening brace, c) eye for tying down the helicopter d) bushing for fastening towing device, e) drain fitting

Cylinder 6 is a steel tube, on the top of which is welded a cap with eyes a for fastening the strut to the part on the fuselage and drain fitting b with its plug. Plunger 7 is fastened to the cap by nut 2 with locking bushing 5. On the cylinder eyes b for fastening the brace and eyes c for tying the helicopter down.

Rod 11 is inserted in the bottom of the cylinder. Rod end 26, having an eye for fastening connecting rod 21, is welded to rod 11. Sleeve 8, in which longitudinal holes are drilled, is screwed onto the upper end of the rod and sleeve 14 with its rubber sealing rings is screwed onto the lower end of the rod.

The lower face of the rod has a radius projection which is intended for locking the wheel in flight with the rod fully extended. The projection on the rod goes into the corresponding slot in catch lock 16, which is fastened with pins (section B-B) in the lower internal part of cylinder 6.

Plunger 7 consists of a tube with holes for foam suppression. Tail piece 3 is welded to the tube and piston 10, having a groove for piston ring 9 and a calibrated hole is located along its axis. Charging valve 1 is screwed into the plunger at the top.

Turning bracket 15 with horn 18 welded to it is mounted on bronze bushings 13 in the upper part of cylinder 6. Bushing d for fastening the towing device is welded into horn 18. Two lubrication fittings are installed for lubricating bushings 13. The turning bracket is held from below by nut 17. The lower hollow of the cylinder is covered by boot 20 which protects the catch lock from dirt.

Connecting rod 21 is fastened to the eyes of rod end 26 and to lever 22 by means of pins which are lubricated through a lubricating fitting installed on the rear side of the eyes.

Lever 22 is connected by its front end to horn 18 of turning bracket 15 with a pin, which is lubricated through a lubricati n fitting and on the other end of the lever is welded an adapter into which the shaft for fastening the wheels is pressed. Indicator 19 showing rod travel and pressure in the oleo cylinder is installed on the pin connecting lever 22 with turning bracket horn 18.

When the helicopter lands, rod 11 moves upward, and therefore liquid from the rod hollow is forced out by piston 10 through its central metering hole. Simultaneously with this, the volume of the nitrogen decreases and its pressure increases in the upper hollow of the cylinder.

The tube of plunger 7 with its holes serves to dampen the stream of liquid and decrease foam formation.

Two unbraked wheels (Fig. 120) are installed on the nose gear. The wheels are mounted on shaft 12 on roller bearings 1 and held on both ends of the axle by nuts 2, which are locked with bolt (uA). The roller bearings are located by spacing bushings 11 and support rings 13, and are covered on both sides of the wheels by covers 3 with dust-protecting plates 7 and 9. The plates are fastened with bolts 8.

The tail skid is intended to prevent the tail rotor blades from striking the ground and to decrease overloads on the tail boom.

The tail skid (Fig. 121) consists of an oleo 32, shoe 30 and two struts 31 which are made of tubes, on the ends of which are riveted mounting parts.

The shoe is fastened to the forked strut connecting part by shaft 12 which is installed on bushings 13. Spring 8 holds the shoe at an angle to prevent its catching during movement along the ground.

The oleo of the tail skid consists of cylinder 18 with a set of sealing rings 25 in its lower part, rod 29 and charging valve 16. Inside the cylinder in its upper part is installed plunger 17, in the lower part of which are longitudinal grooves of varying length on its outer surface, as well as a central metering hole.

There are lateral holes in the upper part of the plunger. Sleeve 21 with valve 22 and piston ring 19 is mounted on the upper end of rod 29.

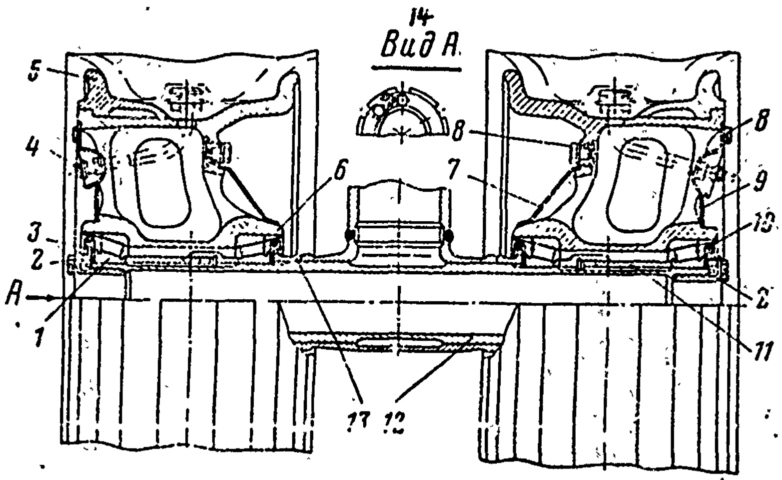

Fig. 120 Nose Gear Wheel Fastening Part:

Key: 1) roller bearing, 2) wheel fastening nut, 3) cover, 4) valve, 5) split rim, 6) wheel drum, 7) plate, 8) plate fastening bolts, 9) plate, 10) felt rings, 11) spacing bushing, 12) wheel axle, 13) support ring, 14) view A

When the tail support strikes the ground, rod 29, moving upward, forces the fluid out of the rod hollow into the hollow of cylinder 18 through the longitudinal grooves on the outer surface of plunger 17. The fluid is also forced into the inner hollow of the plunger through its central opening. The fluid simultaneously passes through the longitudinal holes in sleeve 21 into the circular space between the rod and cylinder, during which valve 22 moves downward. During the rebound stroke, valve 22 covers the longitudinal holes in the sleeve and the liquid passes into the hollow of the cylinder through the holes in the valve and the longitudinal holes in the sleeve.

When the load is removed, the liquid flows backward under the pressure of compressed nitrogen, during which the valve 22 is pressed against sleeve 21.

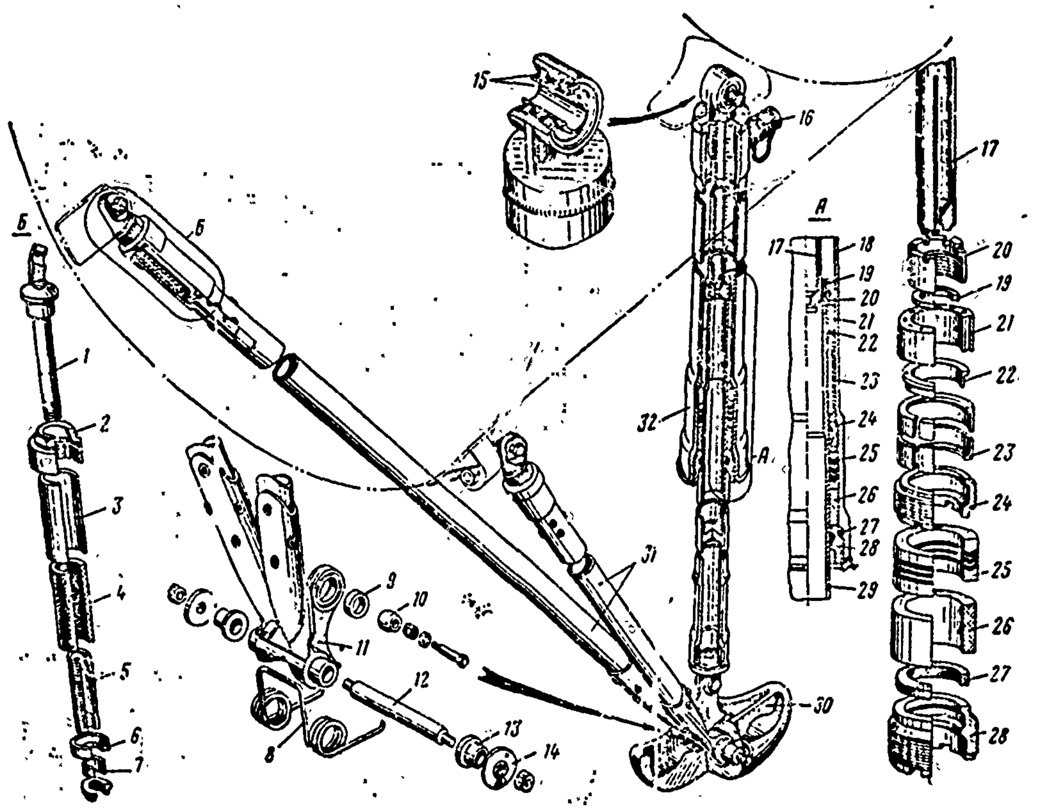

Fig. 121 Construction of the Tail Skid:

Key: 1) eye bolt, 2) nut, 3) outer sleeve, 4) rubber damping bushing, 5) inner sleeve, 6) ring, 7) bushing, 8) spring, 9 and 13) bushings, 10) ball bearing, 11) fork connector, 12) shaft, 14) washer, 15) rubber damping rings, 16) charging valve, 17) plunger, 18) cylinder, 19) piston ring, 20) nut, 21) upper sleeve, 22) valve, 23) bushing, 24) nut, 25) sealing ring unit, 26) textolite lower sleeve, 27) felt rings, 28) nut, 29) rod, 30) shoe, 31) struts, 32) oleo

The total longitudinal section of the holes in valve 22 is less than in sleeve 21.

The lower textolite sleeve 26 and upper sleeve 21 are the guides for the rod during its movement in the cylinder. Ring 27 is located in nut 28 and is intended to clean dust and dirt off the rod.

The oleos are filled with a mixture through a hole in the upper part of the cylinder. A standard charging valve 16, through which the oleo is charged with compressed nitrogen, is screwed into the hole.

Rubber damper 15 which protects the hinge connection from becoming loose is provided in the upper part of the oleo strut.

Section 9

The Helicopter Fuselage

Purpose of the Fuselage and Requirements Outlined for It

The crew, passengers, baggage, cargoes, instruments, equipment and other items are located in the fuselage.

The main rotor, landing gear, tail rotor, engines, empennage, wings and other components are fastened to the fuselage.

[Pages 180 and 181 of the original text are missing.]

blisters, which move backward are installed in the upper portion of each door and provide better visibility during takeoff and landing of the helicopter.

A bulkhead is installed in the front part of the pilot's compartment and the instrument panels for the right and left pilots are mounted on it.

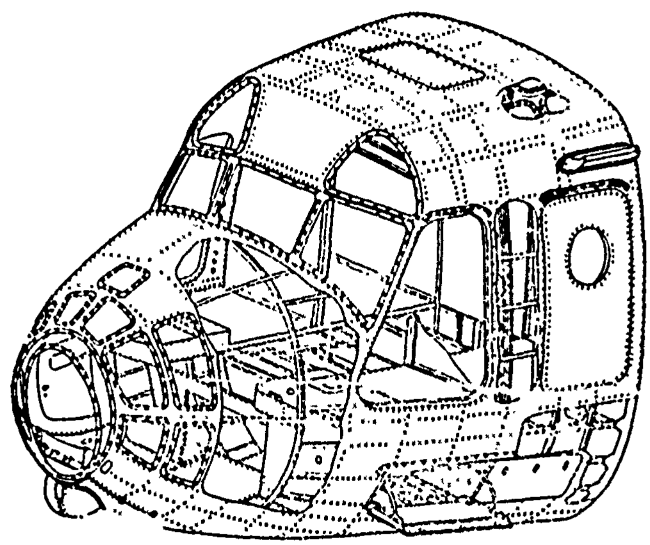

Fig. 125 Nose Part of Fuselage (Pilot's Compartment Emergency Doors not Shown):

The floor framing of the compartment for the pilots, radio operator and flight engineer is formed out of the lower parts of the frames and the longitudinal load-bearing beams. The parts and components of the foot and hand controls, as well as the "pitch-gas" control handle are mounted on the floor. The right and left pilot's seats, which are similar in construction, are mounted on the floor of the cabin to the right and to the left of the passageway.

There are two niches beneath the floor of the pilot's compartment for the storage battery containers, which are installed and located in special guides. The niches are closed off from the outside by two doors which are suspended on hinges and locked with lever type latches.

Due to the presence of special braces, the covers can be set in the horizontal position and used as steps. The containers with the storage batteries are set on the step when they are being removed or installed.

The nose part of the fuselage is assembled as an independent compartment and is butt-joined to the central part of the fuselage along its perimeter with clamping bolts (Fig. 126).

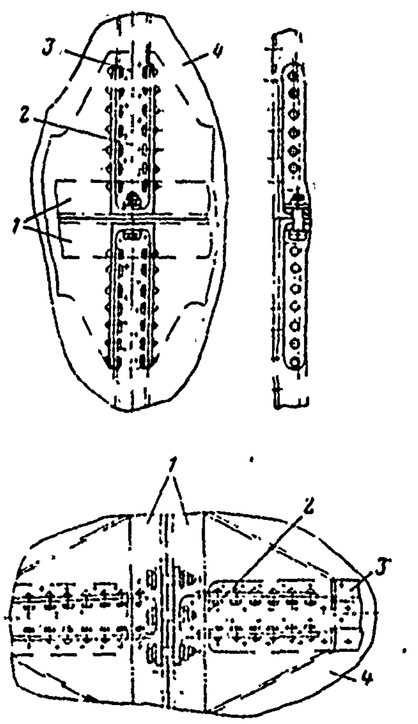

Fig. 126 Butt Joints of Longitudinal Fuselage Elements:

Key: 1) bands of reinforced butting frames, 2) fitting, 3) stringer, 4) skin

The load-bearing framework of the central portion of the fuselage consists of frames, stringers, the load-bearing floor of the cargo cabin and frames in the places having openings. The lower parts of the frames are included in the construction of the lateral framework pieces of the cargo floor.

The upper parts of the frames, located above the ceiling of the cargo cabin, are included in the construction of the fuselage overhead.

The reinforced frames absorb the maximum loads from external forces. All reinforced frames of I-beam section and include a wall with pressed forms riveted to it.

The remaining frames are not reinforced and are manufactured of rolled, Z-shaped forms.

The construction of a typical load-bearing frame is shown in Fig. 127a. The front mounts of the reduction gear frame are fastened to its upper mount. The construction of an unreinforced typical frame is shown in Fig. 127b.

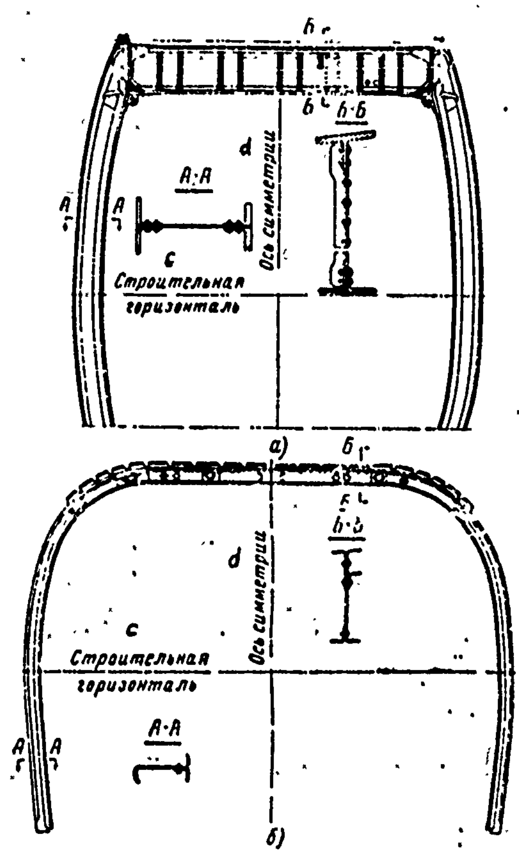

Fig. 127 Frames:

Key: a) load-bearing frame with parts for fastening reduction gear frame, b) typical frame (non-load bearing). c) construction horizontal, d) axis of symmetry

Easily-removed protective panels are installed on the ceiling and on some sections of the walls of the cargo compartment to protect the lines feeding engine equipment, the hydraulic systems, control rods and so forth from incidental damage.

Special ports are made in the outer and ceiling skin, as well as in the skin of the cargo floor to provide accesses and convenience for servicing components of the controls, transmission, reduction gears, fuel and oil main lines, hydraulic system, pneumatic system and other lines.

The hatch covers are made to be either load bearing on self-locking screws or easily-removed non-load bearing, equipped with two lever locks or locks of the pin type with a turning handle. The ports have load-bearing structural elements which form frames at the location of the openings.

The parts for fastening the frame for the main reduction gear are located on the upper cross members of the frames in the corners of the reduction gear compartment. In connection with the fact that these parts absorb vibrational loads, they're stamped of high-strength and vibration-resistant steel.

The load-bearing diagram of the cargo compartment floor is determined by the type of cargo and external loads on the fuselage. For instance, when carrying wheeled transport means, location of the longitudinal load-bearing elements (longerons) of the floor must coincide with the track of their chasses.

The load-bearing framework of the cargo floor in the fuselage scene consists of a longitudinal and lateral set of elements. The lower portions of the frames serve as a lateral set. The longitudinal set consists of two load-bearing beams, symmetrically located relative to the longitudinal axis of the helicopter and made of pressed forms.

The containers for soft fuel tanks are located between the lower portions of the frames. The containers have smooth walls. The base of a container and its ceiling are made in the form of panels with a double skin. Longitudinal diaphragms to provide rigidity of the container and absorb the pressure of fuel in the soft tanks are riveted between the sheets of the skin. To assemble the soft tanks, each container has a removable lateral panel on top, on which the tank plate is fastened. There are cups along the lateral edges of the containers and the tank pins are fastened into them during assembly. To ease assembly

of the fuel lines, there are removable panels in the floor above the containers. The panels are fastened to the floor by screws along their perimeters.

For fastening portable equipment to the cargo floor, connecting parts with rings are installed on the surface of the floor on each side. The parts are fastened to the floor in places where the longitudinal elements are connected with the frames. The hooks of the mooring cables are hooked onto the rings.

In the folded position, the hooks lie in cup-shaped depressions flush with the floor.

A central hatch is located in the cargo floor. To form framing around the place where the opening for the hatch in the cargo floor is located, the longitudinal beams and frames have additional reinforcement in the form of second walls and forms fastened on the corners with fittings.

The covers for the central hatch consist of two upper and two lower doors which are kinematically connected together in pairs. The doors are hung on hinges. In the closed position, the upper doors close onto special locks and make up a common surface which comprises a single unit for placing various equipment and cargoes on them.

The lower doors are kinematically tied with the upper ones by two rods which are adjustable in length. When the hatch is closed, these rods prevent the lower doors from opening In the open position, the doors are held with a special lock.

On the surface of the floor are openings for inspection hatches, the covers of which are fastened along the perimeter by screws.

Loading and unloading cargoes, assault troops, and sick and wounded on stretchers is accomplished through the main cargo hatch in the tail part of the fuselage. The hatch is closed by the cargo doors (Fig. 128).

The doors are made in the form of two framed shells and form the rear outline of the fuselage in the closed position. The doors are hung on hinges. Each door consists of a frame and a skin. The transverse set is made up of frames. The longitudinal set consists of stringers. Horizontal upper and lower beams and a vertical beam lend additional rigidity to the door.

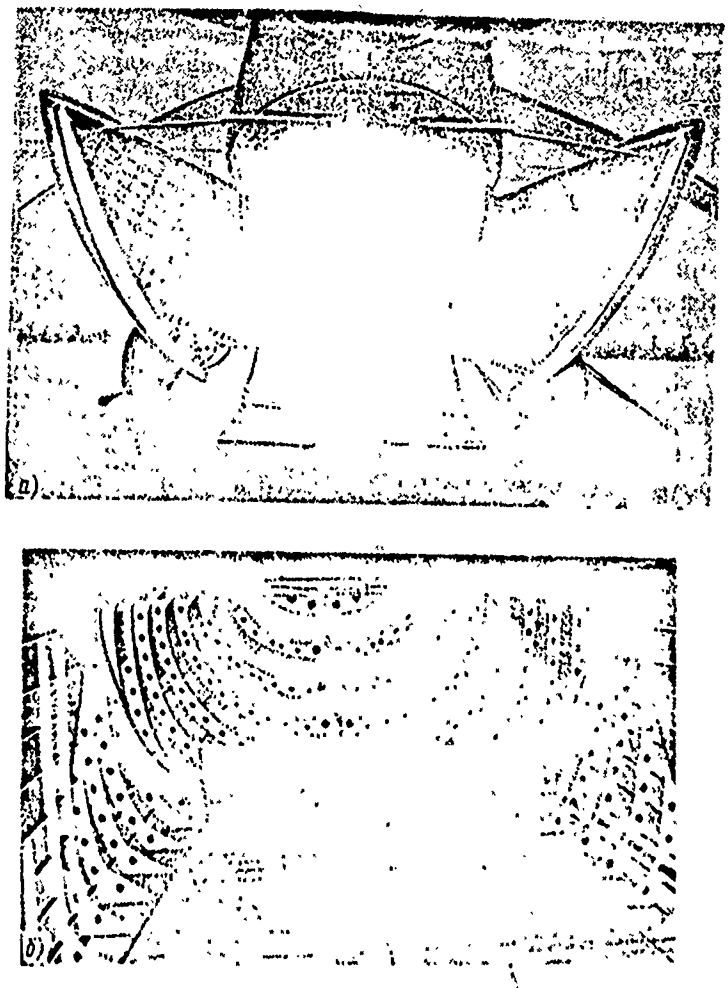

Fig. 128 Cargo Doors and Ramps:

Key: a) in open position, b) in closed position

The cargo ramps consist of two main and two end ramps.

The main ramp consists of longitudinal beams and transverse diaphragms. The upper skin of the ramp is made of corrugated sheet. Transverse plates are riveted to the skin to provide greater strength. The ramps have a smooth skin on the bottom.

The end ramps, which lie with their lower parts immediately on the ground in the lowered position, are hung on the main ramps by hinges.

The slots between the edges of the frame and the main ramp are covered by screens. The screens are hinged to brackets which are riveted to the frame. Rollers are installed on the middle screens and prevent the winch cable from rubbing while drawing cargo into the compartment.

The slots formed between the two main and the two lower ramps when they are lowered are covered by removable ramps.

The doors are opened and closed by using a hydraulic mechanism installed in the upper part of the fuselage. The doors are additionally supported in the closed position by a hydraulic lock which is located on the doors near the opening for the main ramps.

Lowering and raising the ramps is accomplished with a hydraulic mechanism in a definite sequence. The main ramps are lowered after the cargo doors are opened and raised until they lock. The end ramps are set into their working position by a hydraulic cylinder before the main ramps are lowered, and are retracted before the main ramps are raised The hydraulic cylinders with which the main ramps are raised and lowered are installed on brackets beneath the floor of the cargo compartment. There are hatches in the skin of the floor which are covered by easily-removed covers for assembly and inspection of the cylinders. The hydraulic cylinders controlling the end ramps are installed in the rear parts of the main ramps. The main ramps are hinged onto connecting parts to the lower edge of the frame. Each ramp is hung on two joints, the axes of which are inclined upward from the helicopter center line toward its side. Due to this arrangement of the joints, the main ramps, in the lowered position, are spread toward the sides and the track along which a motor vehicle rolls is significantly increased. The angle of inclination of the ramp in the lowered position is 17° - 20°.

Control of the cargo doors and ramps (Fig. 129) is accomplished hydraulically, by means of power cylinders and remotely controlled electric valves in the following order. A rotating switch, located in the flight engineer's cabin, transmits a signal to electric valve 6, which is installed on panel 4. The fluid flows from the valve to cylinder 10, opening (closing) lock-hook 11, which extends door 12. At

the end of its stroke, the piston in cylinder 10 opens a hole through which the fluid flows into cylinder 13.

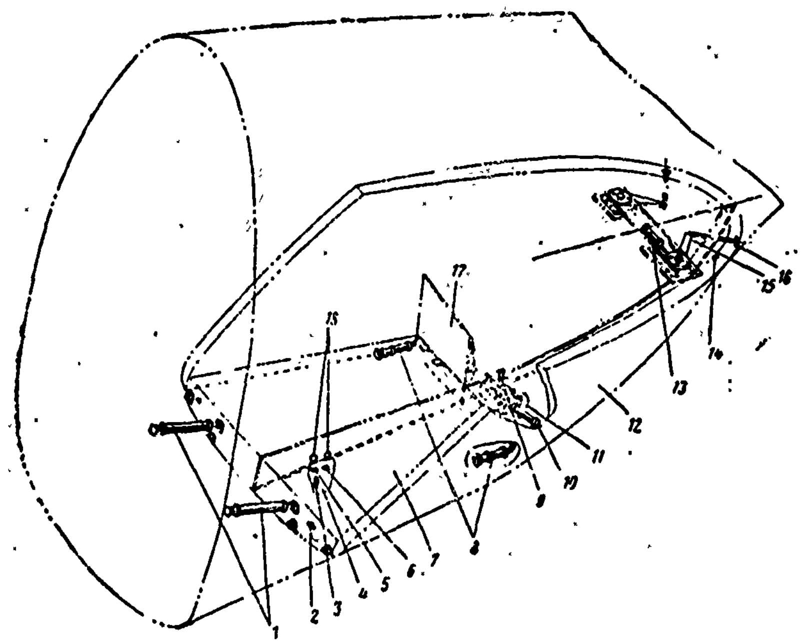

Fig. 129 Installation Diagram of Hydraulic Mechanisms for Opening and Closing Cargo Doors and Ramps:

Key: 1) cylinder for lowering main cargo ramps, 2) cargo ramp limiting switches, 3) hydraulic lock, 4) component panel for controls of cargo ramps and doors, 5) electric valve for opening ramps, 6) electric valves for opening doors, 7) main cargo ramp, 8) cylinders for lowering end ramps, 9) pressure valve, 10) cylinder for closing lock-hook, 11) lock-hook, 12) doors, 13) cylinder for opening cargo doors, 14) limiting switch, 15) lever, 16) rod, 17) end ramp, 18) valves for manually opening cargo doors and ramps

Cylinder 13 opens the doors with lever 15 and rod 16. At the end of its stroke, the rod of cylinder 13 presses limiting switch 14, which transmits a signal to electric valve 5, feeding liquid into cylinder 1 for lowering cargo ramp 7 and cylinders 8 for unfolding end ramp 17.

To ensure the proper sequence in lowering main cargo ramp 7 and end ramps 17, braking of the fluid moving out of cylinders 1 is provided with a check valve which has an apperature on the working surface of the valve. The valve performs braking only when the ramps are being lowered, and when they are being raised, it does not participate. Due to braking in cylinders 1, the liquid first moves into cylinders 8 of end ramps 17, unfolds them and then they are lowered to the ground together with ramp 7.

For raising the ramps and closing the doors , it is necessary to turn the tumbler in the other direction. The switch goes from the tumbler to valve 5, feeding liquid into cylinder 1 to raise the main ramp 7 and end ramp 17. When the ramps are fully raised, two interlocking limiting switches 2 are pressed and feed a signal to valve 6, after which the liquid flows into cylinder 13 for closing the doors. When the doors are nearly closed, they press on hydraulic pressure valve 9, which feeds liquid into cylinder 10 for closing lock-hook 11. After the doors are closed, the limiting switch is pressed, extinguishing the red lamp. Turning the red lamp off indicates that the doors are closed.

Hydraulic lock 3 is installed in the line for raising and lowering the ramps and holds the ramps in the raised position if fluid pressure in the hydraulic system falls.

The capability is also provided for opening the cargo doors and ramps with valve 18, which connects both hollows of the cylinders controlling these doors and ramps with a drain. In this case, the lock is opened with a special wrench.

The helicopter is equipped with a special device for transporting large cargoes which are suspended outside.

The installation consists of a lock and hydraulic cylinder fastened on struts 8 (Fig. 130).

Electric winch 1 is fastened forward, on the floor of the fuselage cargo cabin. When the winch is used for external suspension, its cable is passed through extension roller 2 and lock-swivel 3, after which lock-catch 4 is installed on the end of the cable. The lock-catch is connected to a connecting tip on sling 5, on the end of which is fastened hook 9.

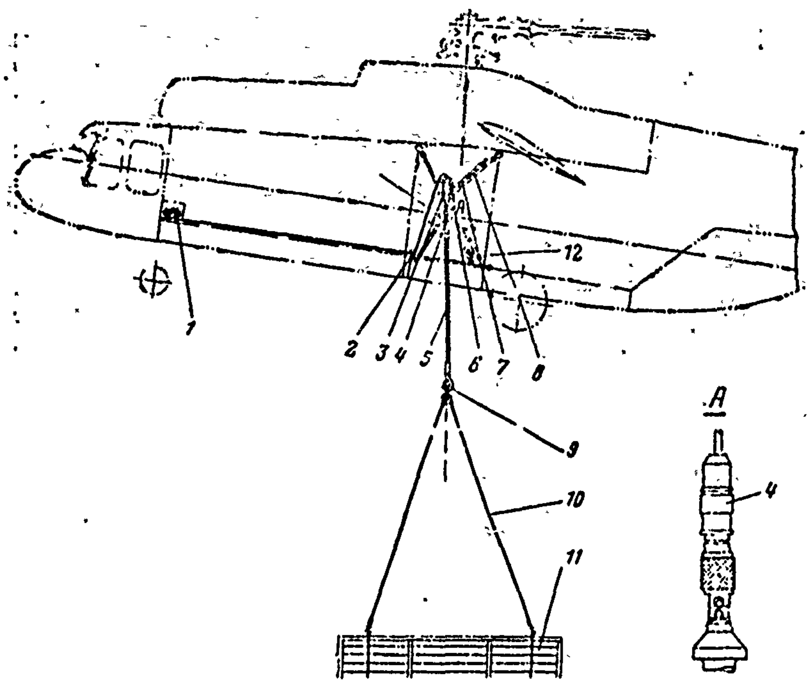

Fig. 130 Diagram of Installation for External Suspension of Cargoes:

Key: 1) winch, 2) extension roller, 3) lock-swivel, 4) lock-catch, 5) sling, 6) hydraulic cyliner, 7) emergency cargo release handle, 8) strut, 9) hook, 10) cargo sling, 11) cargo, 12) guardrail

Guardrail 12, which is in the form of a girder fastened to the floor of the cargo compartment with braces is provided to ensure safety during operation of the installation. Rods holding the doors of the cargo floor hatch in the open position are installed on the guardrail.

Cargoes can be suspended on a special installation manually on hooks 9 and removed with the helicopter hovering above the ground at a low height. In caseswhere it is necessary to suspend a large cargo and access to hook 9 is difficult, hookup of cargo 11 is provided with sling 10 and a cable which is wound onto winch 1.

During cargo hookup, the helicopter lands along side of the cargo or behind the cargo and then the winch cable with lock-catch 4 is payed out. The lock-catch is manually fastened onto a connecting tip of sling 5. After the helicopter takes off and hovers above the cargo, winch 1 is turned on to retract the cable, bringing the helicopter closer to the cargo. At the end of the cable run, lock-catch 4 presses on a limiting switch, which automatically turns off the winch and locks the sling in the lock-swivel with a hydraulic cylinder. The hydraulic cylinder is fitted with a ball lock which automatically opens when the cargo is manually released.

The electric winch is controlled from the side of the helicopter with a movable panel. The open position of the lock is signaled by a burning lamp, indicating termination of cargo suspension.

The lock-swivel is hung on a universal hinge, allowing it to rock in the longitudinal and lateral planes

To avoid twisting a cable with a cargo suspended, one supporting and two radial ball bearings are installed in the lock-swivel. Supporting bearing absorbs vertical loads from the suspended cargo and allows it to turn relative to the vertical axis. The radial ball bearings absorb lateral loads when the cargo is rocking.

If the helicopter jerks sharply, forces can arise in the winch cable which would lead to its breakage. To eliminate this, a device which automatically frees the sling head is provided in the lock-catch.

If necessary, the cargo can be dropped during flight using an electric button which is located on the left hand helicopter control lever, or by switching the emergency tumbler which is located on the left instrument panel. In case the electric control fails, manual cargo dropping is provided by means of opening a hydraulic valve, and in case the hydraulic system fails, the cargo can be dropped by opening the hydraulic valve and turning the emergency release handle downward.

The tail boom of the fuselage has the form of a sectionec cone and consists of a set of frames and stringers, and also a skin (Fig. 131). For convenience in manufacturing, the tail boom has a longitudinal technological joint, allowing separate removal of each half of the boom.

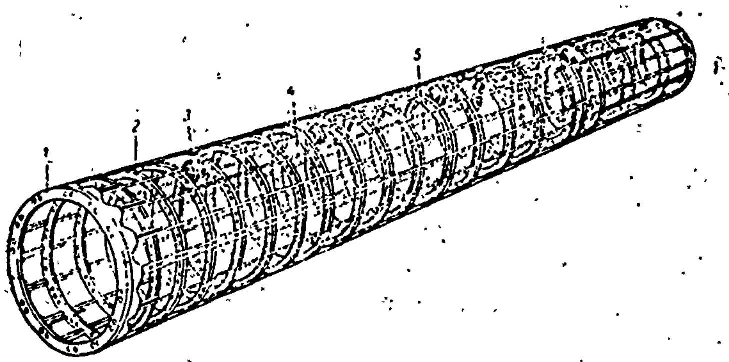

Fig. 131 Tail Boom:

Key: 1) load-bearing "butting" frame, 2) non-load-bearing frame, 3) tail shaft support, 4) stringer, 5) skin

The transfer set of the boom consists of two butting face frames 1 and non-load-bearing frames 2, which are located along its entire length. Frames 1 are manufactured of pressed angles. The frames to which tail shaft support 3 are fastened are reinforced with fittings.

Stringers 4, installed at the bottom and also on the left side of the boom (in the zone of compression) are spaced more frequently and have a larger cross sectional area by comparison with those on the upper right side of the boom.

A thicker skin is also installed in the zone of compression. The sheets of skin 5 are connected by overlapping. The longitudinal butts of the skin are located on the stringers and have a two-row riveted seam, while the lateral ones are located on the frames and have two- or three-row riveted seams.

The parts for fastening the stabilizer are installed on the tail boom.

The tail boom is connected to the central part of the fuselage by the bolts fastening the face frames with the fittings on the ends of the stringers.

To decrease stress concentrations in the skin in the area of butting, a band of duralumin sheet is laid beneath the fittings along the entire perimeter of the face frames.

The tail boom is fastened to the end boom in the same way as it is fastened to the center part of the fuselage.

The end boom is a continuation of the tail boom and has a bend upward in relation to the tail boom center line.

Cabins

The crew cabin is located in the nose portion of the helicopter's fuselage. The makeup of the crew cabin is determined by the purpose of the helicopter. In the light helicopter, the crew consists of one pilot. Two pilots and a flight engineer are located in the crew cabin of a medium helicopter. In a heavy helicopter, the crew consists of two pilots, a navigator, radio operator and flight engineer.

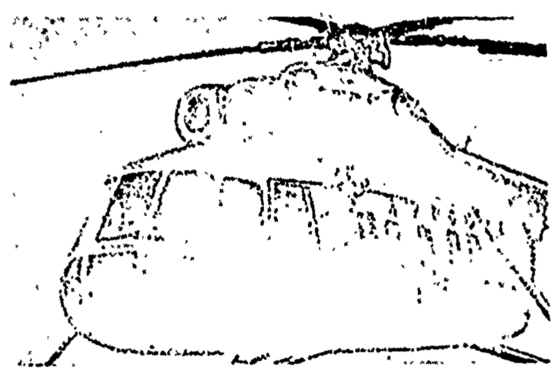

Fig. 132 Nose Portion of the Fuselage

A passenger or cargo, depending on the purpose of the helicopter, are located in the central part of the fuselage.

The crew cabin must have good visibility forward, to the side, upward and downward. Visibility downward is necessary in a helicopter while hovering and landing with a steep descent. Fig. 132 shows the nose part of a helicopter, which is the crew cabin.

The heating and ventilation system of a passenger helicopter is shown in Fig. 133. The heating and ventilation system provides the feed of heated or outside air into the passenger cabin and into the crew cabin, and heat is provided for the pilot's legs, defrosting the front windshield and blisters in the crew cabin, and also for heating the condensation trap in the helicopter's air system.

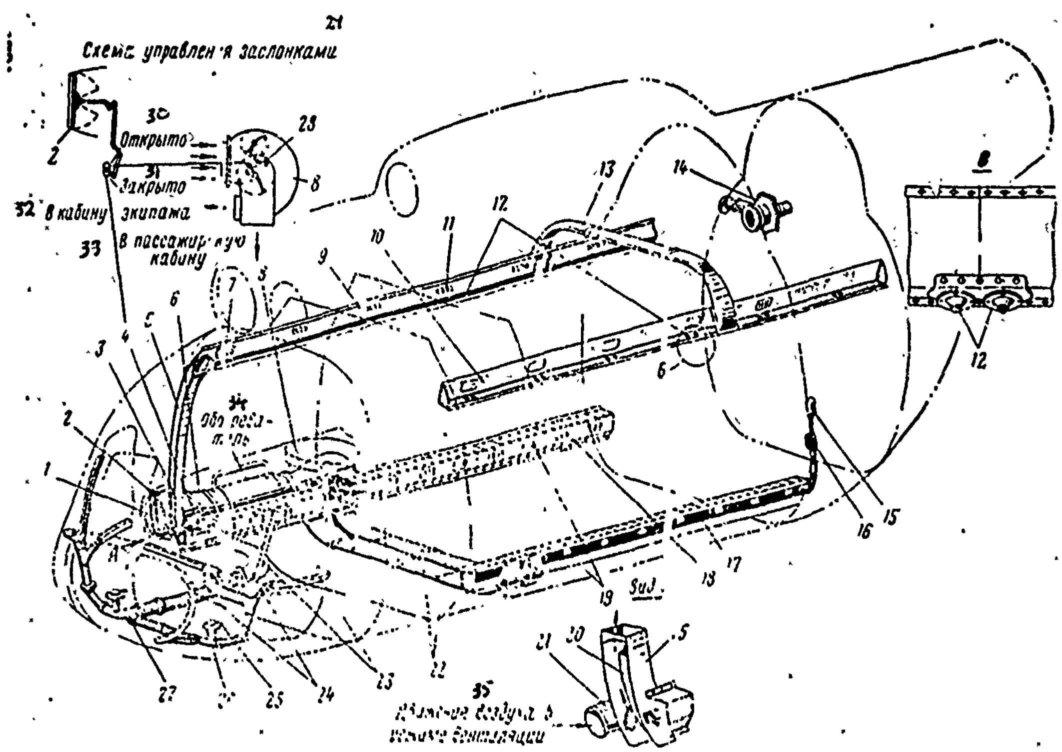

Fig. 133 Cabin Heating and Ventilation Diagram

Key: 1) screen, 2) air intake flap, 3) handle controlling distributor flaps, 4) handle controlling air intake flap, 5) vertical pipe, 6) heater fan, 7) flap, 8) distributor, 9) right ventilation box, 10) left ventilation box, 11) movable flap handle, 12) individual passenger air pipes, 13) lateral pipe, 14) fan, 15) air system condensation trap, 16) trap heating pipe, 17) left heater box,

Key continued on following page.

Key for Fig. 133 continued:

18) right heater box, 19) heater box flaps, 20) recirculation feed pipe, 21) intake pipe, 22) connector pipes, 23) windshield and blister defrosting boxes, 24) connecting main line, 25) flap handle controlling air feed to pilot's legs, 26) flap of air feed to pilot's legs, 27) front pipe, 28) differential mechanism, 29) diagram of flap control, 30) open, 31) closed, 32) to crew cabin, 33) to passenger cabin, 34) heater, 35) air movement during ventilation

The basic component of the system is a kerosene heater which is suspended on the outside in the cowl-fairing which is a continuation of the suspended fuel tank on the right side.

When the heater is one, heater fan 6 collects air from the atmosphere through the heater cowling air intake, and for accelerated heating (recirculation), air is collected from the passenger compartment through a window in the ventilation box, which is covered by plate 7. The plate is held in the closed position by a spring.

In the recirculation mode, plate 2 of the heater cowl air intake is closed. Air then flows from the passenger compartment into vertical pipe 5 through a window in the ventilation box, opening plate 7. Further, the air, passing through a hole in the outer skin of the fuselage, enters pipe 21 and goes to heater fan 6.

Control of plate 2 is accomplished from the passenger cabin by handle 4, which is located in a special compartment of the heater box. If plage 2 is open, air flows through screen 1 to the heater immediately from the outside atmosphere. Intermediate positions of this flap, corresponding to partial recirculation, are also possible and allow air to be collected both from the atmosphere and from the passenger cabin simultaneously.

Warm air flows from the heater into outlet distributor 8, in which the air is divided into two streams: into the passenger compartment and into the crew cabin.

For heating the passenger cabin, warm air flows from the distributor into heating box 18 and along connecting pipes 22 which lie beneath the cabin floor into heater box 17. Air flows into the crew cabin from the distributor

along main line 24.

Two plates which are kinematically connected together by a differential mechanism and controlled by a common handle 4 are installed in the outlet distributor. Depending on the position of the plates, warm air can flow either into the passenger compartment or into the crew compartment, or can flow into both compartments simultaneously in various proportions.

On the boxes are holes, covered by plates 19, for exhausting hot air. The degree to which these plates are opened is adjusted during installation of the system on the helicopter for the purpose of obtaining an equal field of temperature throughout the entire cabin.

A pipe ending with air nozzles 16 comes out of the rear face of the left box. The air nozzle is located beneath the condensation trap 15 of the helicopter's air system. Warm air flows immediately from the pipe to heat the trap.

Main line 24, connecting distributor 8 with the crew cabin, passes to front pipe 27. Here, the main line splits and passes to windows in the crew cabin floor. The windows have plates 26 for exhausting warm air near the foot control pedals of both pilots. On the sides of the crew cabin, a branch of the main line ends in boxes 23 which are hung onto the cabin window framing. A stream of warm air is directed from both boxes onto the front windshield and boosters through holes made in the walls of the frames.

In the ventilation mode, plate 2 is opened and heater fan 6 is turned on without supplying fuel to the heater. In this case, air is collected from the atmosphere through the air intake and flows (without being heated) into outlet distributor 8, and then flows into the cabin along the same passages as during the heating mode. Besides this, air from the atmosphere flows by the force of velocity into inlet pipe 21 and is directed along pipeline 5 into ventilation boxes 9 and 10, which are connected together by pipelines 13. Fresh air flows from the ventilation boxes into the passenger compartment through holes, covered by plates which can be manually moved by handles 11.

The ventilation boxes are located beneath the ceiling of the cabin. They are fitted with individual passenger ventilation pipes 12 (part B).

The presence in the heater box of pipe 20, which is made in the form of an air nozzle, allows warm air from the heater box to be mixed with air from the atmosphere which flows by velocity pressure through intake pipe 21.

The helicopter is equipped with exhaust ventilation, which provides forced pumping of air from the passenger compartment. A centrifugal fan, driven by an electric motor, is installed for this purpose. Air is sucked out of the wash room and flows along pipes to the outside, overcoming the resistance of plate springs. When the fan is switched off, plate is automatically closed by the spring, preventing penetration of engine exhaust gases into the passenger compartment.

Helicopters intended for operation in regions with a warm climate are equipped with two on-board freon air conditioners.

The following basic parts go into each air conditioner unit (Fig. 134): compressor 8, electric motor 7, condenser block 11 and fan, evaporator 1 with its electric motor and two fans, receiver 10 and filter-dryer 9. With the exception of the evaporator, the components of the air conditioners are located in gondola 5 and are assembled one behind the other.

Evaporators 1 are installed in the passenger compartment on baggage shelves.

The condenser and compressor fan of each unit has a pulley on its shaft which is connected to electric motor 7 by a V-belt.

The evaporator has holes into which frames with guide blades are inserted. The frames can be turned to any angle, providing the possibility of adjusting the direction of cold air flowing from the evaporator. On the evaporator panel are two control handles. One handle is to engage the electromagnetic clutch with the compressor and to control the number of electric motor revolutions. The electric motor turns the vaned evaporator fan. The exhaust of air passing through the evaporator can be changed by turning the handle. By turning the second handle, it is possible to control the thermostatic fan and change the air conditioner's production of cool air.

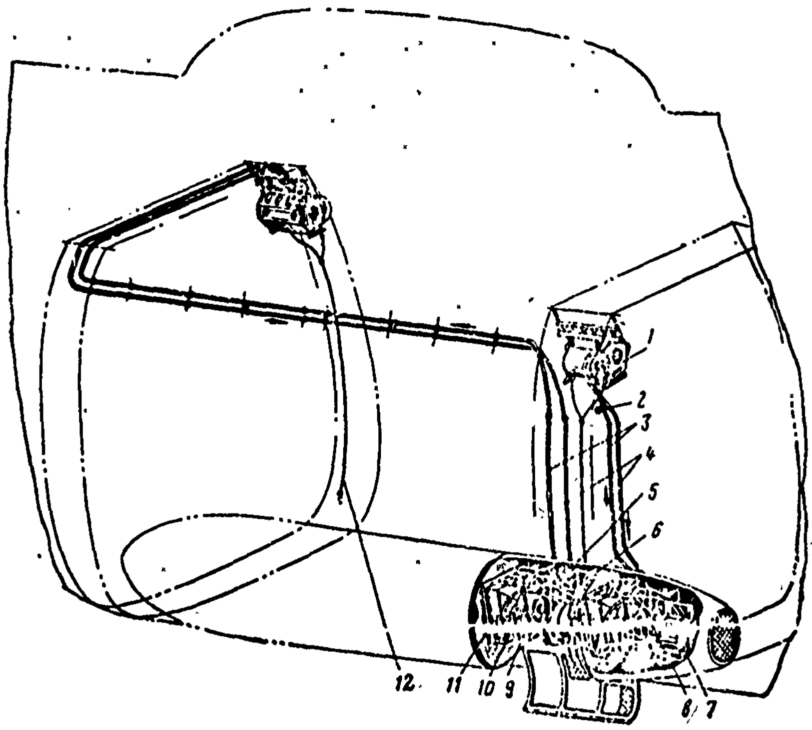

Fig. 134 Installation of On-Board Freon Air Conditioners:

Key: 1) evaporator, 2) pressure signalling sensor, 3) pipelines with liquid freon, 4) pipelines with freon gas, 5) gondola, 6) bulkhead, 7) electric motor, 8) compressor, 9) filter-dryer, 10) receiver, 11) condenser block, 12) drain pipe

The lower part of the condenser is made in the form of a trough where water condensation forms on the pipes of the evaporator radiator drains. The trough is connected with a drain pipe through which the condensation is carried outside the helicopter. The overboard drain pipe outlets are made lower than the line of the floor and are covered with plate-deflectors which reduce pressure on the drain pipe outlet.

The electric motor for each condenser is turned on and off separately with a switch located on a panel by the right pilot.

Work of the condenser is monitored by means of a pressure signalling device, whose sensor is installed on the pipeline with liquid freon. In case freon pressure falls, a signal lamp located in the crew cabin lights up.

Chapter III

Brief Information on the Process of Designing Helicopters

1. The Basic Tasks of Helicopter Design

The selection of a helicopter's layout, determination of its total weight and payload, and determination of its basic parameters have come to be called overall helicopter design.

Determination of the weight of construction components of the helicopter, determination of the parameters and selection of construction and load-bearing diagrams are called component planning of the helicopter.

The entire range of knowledge necessary for planning a modern helicopter was accumulated as a result of many years of work by specialists of various countries -- aerodynamicists and strength experts, and also as the result of planning, production and operation of helicopters. Helicopter design consists of the development of engineering documentation determining the flying and engineering characteristics of a helicopter, and the construction of the helicopter and its basic components.

The desired flying characteristics of a new helicopter are formulated by the purchaser in the form of special requirements.

During planning, the designer must strive so that the new helicopter fully satisfies the requirements outlined for it.

The process of designing a helicopter is extremely complex and demands great ingenuity and varied design research on the part of the designers. The basic task in designing a helicopter is the correct choice of its layout, engine, transmission type, main rotor parameters and dimensions of other parts of the helicopter which provide achievement of the assigned flying data.

Some of the chief indices for good helicopter design are its high flying and engineering data, and its reliability and economy in operation.

Much significance has been given to questions of comfort in the passenger compartment -- noise level, vibration, and air composition -- must be within limits required by health and engineering norms.

The helicopter must have required flying properties -- a given static ceiling with consideration for possible deviations in air temperature and humidity, and a given horizontal airspeed at a definite altitude. The helicopter must be able to be engineered into series production, allowing maximum usage of modern mechanization of production process for parts, components and assembly. The following essential problem in helicopter design must be considered:

a) high safety factor in parts and components of the helicopter;

b) convenience of loading and unloading passengers and cargoes on the ground and while the helicopter is hovering;

c) minimum number of lubrication points and required types of lubricant for injected hinge connections.

The crew must have good visibility while taking off and landing the helicopter, and, for hoisting operations, in the hovering configuration.

In designing a special purpose helicopter, specifics stipulated for its tactical and technical requirement must be considered.

When designing a helicopter, it is desirable to make maximum use of parts and components of existing helicopters

which have been proven in operation.

The design for a new helicopter must always be a step forward in the area of helicopter development.

Engineering Requirements for Helicopters

In the basic drawings, the helicopter being designed is fully defined by engineering requirements.

The engineering requirements are formulated by the purchaser and agreed on by the firm accepting the order for the helicopter design. The engineering requirements formulated on the basis of analysis of existing achievements in corresponding branches of technology such as, for instance, engine building and metallurgy, electronics, and also on the basis of accumulated experience in domestic and foreign helicopter construction with considerations for prospectives of developments in the use of helicopters in the national economy.

Engineering requirements indicate the purpose of the helicopter, the type of engines and their number, the type of payload and its dimensions, the crew, service ceiling under given atmospheric conditions, cruise speed at a given flight altitude, flight range or endurance at a given power setting and rate of climb.

Operational requirements include the methods of loading and unloading cargoes transported in the cargo cabin or on external suspensions and methods of securing the cargo during flight. Requirements for passenger compartments are determined by corresponding safety and engineering norms.

The payload is given in the form of a list which indicates the composition of the flight crew, the number of passengers, baggage, the weight of cargo and its displacement, removable requipment and so forth.

The technical requirements also indicate the allowable vibration of the helicopter in frequency and in altidute, and also limiting atmospheric conditions (temperature, humidity) of operation. These requirements are considered in the process of designing corresponding parts, hinges, fastening fittings and the hydraulic system of the helicopter.

Section 2

Planning Stages

The entire process of planning a helicopter can be broken down into three basic stages. 1) sketch plan; 2) preliminary plan with construction of a mockup and 3) execution plan for manufacture of working drawings. These stages do not have clearly defined limits and often overlap each other.

The sketch plan provides the original material for subsequent stages of planning. The basic parameters of the helicopter are determined according to engineering requirements given by the purchaser. Several variations of sketch plans are worked out for the given engines. On the basis of analysis of the achievements and deficiencies of a given plan, a plan is established which must fully correspond to the engineering requirements.

During sketch planning, all computations are made according to approximate formulae, in which only the first-stage parameters are considered.

The major part of the sketch plan is the configuration drawing for the helicopter.

The preliminary plan is executed after the sketch plan is affirmed. Aerodynamic calculations are made more accurate in this stage. Models of the helicopter and its basic parts are tested in a wind tunnel.

The basic parts and components of a helicopter are planned, strength computations are made and section dimensions for the load-bearing elements are selected. The weight of the helicopter and its center of gravity are made more precise. Calculations on the longitudinal static strength are made and balancing curves for all flight configurations are constructed.

The frequency characteristics of the blades, fuselage, transmission, controls and landing gear are determined for the purpose of eliminating resonance oscillations.

On the basis of all computations and research in the configuration drawing, necessary changes are made, after which a mockup of the helicopter is constructed out of wood. The fullness and quality of execution of the engineering requirements are checked on the mockup.

The execution plan contains design developments of all parts and components, as well as working drawings produced in a definite sequence with consideration for the technical process of assembling the helicopter.

Framed constructions undergo static testing under loads corresponding to the strength norms for helicopters.

Parts, components and assemblies working under dynamic loads (blades, the hub, dampers, parts of the controls and transmission and so forth) must be subjected to fatigue testing. The characteristics of the blade dampers gear oleos, and hydraulic power cylinders are checked. The control of weight has great significance in the process of developing working drawings. It consists of comparing and tying together the design weight of the helicopter with the weight attained by detailed computation of weights according to the drawings. Both overweight and weight distribution which is outside certain limits are highly undesirable for a helicopter. Overweight construction will lead to a decrease in payload and an increase in the helicopter's cost. Out-of-limits weight distribution will lead to a change in the center of gravity of the helicopter by comparison with its earlier-determined position.

Section 3

The Composition of the Sketch Plan

Sketch planning consists of determining the basic parameters of the helicopter and the parts of its construction. The sketch plan allows determination to be made of the feasibility of future planning, keeping in mind the degree to which the helicopter under design corresponds to the requirements of the purchaser. As a rule, the helicopter is designed for a specific engine.

The following go into sketch planning for a helicopter:

1) Analysis of statistical data of single-type helicopters;

2) Selection of a layout for the helicopter and determination of its parameters;

3) Development of the overall appearance, configuration of the helicopter and overall views of the construction of the most important parts of the helicopter;

4) Approximate calculations on strength of the most important parts of the helicopter;

5) Computations for weight and center of gravity;

6) Aerodynamic computations and computations of stability;

7) Selection of the control system.

This listing of tasks in the sketch planning also reflects the sequence of these operations during the course of the sketch planning.

Analysis of statistical data of single-type helicopters provides the necessary material for actual planning. Sometimes, the experience accumulated and corresponding material on planning and operation of single-type helicopters has a decisive meaning.

The layout of the helicopter is selected after comparing several sketch plans of helicopters which are executed to the same engineering requirements. After careful analysis of the advantages and disadvantages of the sketch plans reviewed, a variation is chosen which corresponds to the highest degree to the requirements of the purchaser. The basic parameters of a helicopter must be selected in such a manner that all engineering requirements are fulfilled and maximum use is made of parts and assemblies which are proven in practice. The latter is necessary to keep the so-called finish work to a minimum and create a machine in the shortest period of time with the minimum possible expenses.

The main part of a sketch plan is the configuration of the helicopter. Approximate methods of determining the flying characteristics of the helicopter are used during sketch planning. Calculations on the strength of the most important pa of the helicopter and the weight calculations are also made according to approximate formulae.

Selection of the Helicopter's Layout

Selection of the layout of a helicopter is determined to a significant degree by the technical requirements of the purchaser. The final decision of the question on the helicopter's layout makes it necessary to develop sketch drafts of helicopters (according to layouts which most fully correspond to the technical requirements). A well-founded selection of the layout can be made by means of analyzing the characteristics of helicopters in great detail.

Up to a determined amount of takeoff weight for the helicopter, the question on its layout is most often decided using the single-rotor layout, while with a very high takeoff weight, a two-rotor or other layouts are used.

Depending on the primary purpose of the helicopter, preference is given to a corresponding criterion, for instance, maximum reliability and economy in operation, simplicity of construction and low cost of the helicopter, high range, speed and ceiling or extended hovering and low speed and range.

Preliminary Determination of the Takeoff Weight of a Helicopter

The empty weight of a helicopter G_e consists of the weight of the helicopter's construction G_c, the weight of the main rotor G_{mr}, the weight of the power plant G_{bp}, the weight of the transmission G_{tr}, the weight of fittings G_{fi}, which consists of the weight of the equipment G_{eq} and the weight of auxiliary equipment G_{ae}. The gross loading weight G_l consists of the weight of the crew G_{cr}, the weight of fuel G_f, the weight of the payload (passengers, cargoes) G_{pl} and the weight of the service load G_s.

The main roter and its controls are not included in the power plant of a helicopter since they are independent construction parts. Therefore, the weight of the power plant G_{pp} includes the weight of the engines, the engine mounts, cowlings fairings, gondolas, engine cooling system and its parts, the lubricating and fuel system, installations for air intake and exhaust, systems for controlling and monitoring the work of various assemblies of the power plant and the fire prevention installation.

The weight of the equipment G_{eq} includes the weight of aerial navigation equipment, electric and radio equipment, radio location and oxygen equipment.

The weight of the auxiliary equipment G_{ae} includes the weight of the anti-icing and heat-and-sound insulation, the weight of permanently installed equipment and the weight of hydraulic and pneumatic systems.

The weight of service loading G_{se} includes the weight of products in the galley, water in the bathroom and so forth.

Writing all this in the form of an equation, we obtain

$$G_{to} = G_c + G_{mr} + G_{pp} + G_{tr} + G_{fi} + G_{cr} + G_f + G_{pl} + G_s.$$

If both sides of the equation are divided by G_{to}, we obtain an equation for the relative weights of the helicopter

$$\bar{k}_c + \bar{k}_{mr} + \bar{k}_{pp} + \bar{k}_{tr} + \bar{k}_{fi} + \bar{k}_{cr} + \bar{k}_f + \bar{k}_{pl} + \bar{k}_s = 1$$

Introduction of the understanding of relative weight allows the preliminary (approximate) determination of the gross weight of the helicopter G_{to} to be significantly simplified.

G_{eq}, G_{cr}, G_s and G_{pl} are accurately determined from all the components of maximum gross weight G_{to}. For this, it is necessary to have accurate requirements for fittings, for the number of crew members and for loads.

These requirements are usually shown in the order for the design.

Knowing the gross loading weight

$$G_l = G_{pl} + G_f + G_{cr} + G_s + G_{eq}$$

(where G_{eq} is the removable equipment) and the coefficient of load ratio $\bar{k}$ equals G_l / G_{to}, we determine the takeoff weight of the helicopter.

We obtain the relative weights from statistics and, knowing the takeoff weight of the planned helicopter, we determine the weight of the remaining components.

The coefficient of load ratio $\overline{k}$ is taken from statistics from helicopters of the same type as the one being designed. Helicopters of the same weight category being compared must have an identical parameter of "flyability" $q\sqrt{p}$, where $q = G_{to}/N$, which is the load per engine power; $t = G_{to}/S$, which is the load per area encompassed by the main rotor.

Then, the helicopters must have approximately identical flying characteristics at vertical rates. If this is disregarded, it is possible to make a mistake, considering a helicopter design to be successful in which the high load ratio is obtained by overloading. This helicopter would not be able to take off vertically.

The coefficient of load ratio $\overline{k}$ of helicopters equipped with turbine engine and mechanically driven main rotors is higher than in the same helicopter having a piston engine due to: lower weight of the engine itself, decrease in lubricant consumption and the decrease in radiator weight connected with it, the absence of a clutch, exhaust collectors, fan and cowling for it.

Determination of the Basic Parameters of a Helicopter

The parameters of a helicopter which may be considered the basic ones are to a significant degree determined by the engineering requirements for the given helicopter. Some parameters are defined for all helicopters designed. These include:

Load on the area described by the main rotor, $p = \frac{4G_{to}}{\pi D^2}$;

Load on the engine power, $q = G_{to}/N$.

These two parameters are in a definite dependency on each other and characterize the power engineering quality of the helicopter

$$q\sqrt{\frac{p}{\Delta}},$$

where Δ -- value depending on the flight alti ude.

The higher this quality, the better the helicopter and the less power is required to support the helicopter in the hovering mode.

We will explain this conslusion.

According to the Wellner, the thrust of the main rotor is determined from the following expression

$$T_{mr} = (75\sqrt[3]{\varrho\frac{\pi}{2}}\,\eta_{re}N_r D)^{\frac{2}{3}},$$

where $\eta_{re} = \dfrac{c_\ell^{\frac{3}{2}}}{2m_k}$ -- relative coefficient of efficiency of the rotor while hovering;

$c_\ell = \dfrac{2p}{\varrho(\omega R)^2}$ -- coefficient of lift of the main rotor;

$m_k = \dfrac{8M_{tm}}{\varrho(\omega R)^2\pi R^3}$ -- coefficient of main rotor torque moment;

$N_r = \zeta N$ -- power to the main rotor;

ζ -- coefficient of power usage;

ϱ -- air density;

M_{tm} -- main rotor torque moment;

D -- main rotor diameter.

In the hovering regime at sea level, $\varrho_0 = 0.125$ and $T_{mr} = G_{to}$.

After corresponding substitutions in the formula for thrust T_{mr}, we obtain

$$\left(q\sqrt{\frac{p}{\Delta}}\right)_{re} = 37{,}5\zeta\eta_{re}$$

It is evident from this equation that it is necessary to strive for the largest possible relative coefficient of efficiency of the rotor while working in the hovering regime and for the minimum power loss in the train from the engine to the main rotor hub (which is to say to have the largest value for the coefficient ζ).

The relative coefficient of efficiency of the main rotor η_{re} depends on the geometric parameters of the rotor: airfoil characteristics, blade bending and angle of setting, and also the solidity of the main rotor

$$\sigma=\frac{kb_{0,7}}{\pi R},$$

where 0.7 -- chord of the blade section at a distance of 0.7 R;

k -- number of blades;

R -- main rotor radius.

In selecting the parameters of the main rotor, one strives to attain a situation in which the maximum horizontal airspeed of the helicopter at a given altitude does not cause stalling in the retreating (moving along the air stream) blade.

From the expression

$$G_{t/o} = 37{,}5\eta_{re}\zeta\frac{N}{\sqrt{p}}$$

it is evident that the amount of cargo lifted by the main rotor is inversely proportional to the value $\sqrt{p}$, which is to say that an increase in load p per area described by the main rotor will lead to a decrease in the takeoff weight with the same engine power.

The amount of load p determines the vertical speed of the helicopter when reduced to the autorotation configuration. The vertical speed during autorotation is expressed by the following formula:

$$V_y=-1{,}48\sqrt{\frac{p}{\Delta}}.$$

With a given load p on the main rotor area described, the diameter of the main rotor is determined according to the formula

$$D=\sqrt{\frac{4G_{t/o}}{\pi p}}.$$

If value D turns out to be inconveniently large in dimensions and in weight, either the load on the main rotor area described is increased or the design is changed to a multi-engine installation, or changed to a multi-rotor layout if the first decision does not provide the needed result.

Specific loads per power q required for hovering and for a given vertical takeoff airspeed are determined according to the parameters q $\bar{p}$. The required power N of the power plant of the helicopter being designed is determined according to q.

Main rotor tip speed ωR is selected in such a manner that at maximum airspeed, the retreating (moving along the air stream) blade will not stall and the advancing blade will not encounter wave resistance.

In the hovering regime, the tip speed of the main rotor must be such that its coefficient of efficiency is sufficiently high.

Having attained an allowable value for the relationship c_l/σ from conditions of inadmissable stalling on the blade end at maximum helicopter airspeed, considering flight altitude, the coefficient of solidity σ is determined.

Selection of the Engine

The type and number of engines for the helicopter being designed are sometimes included in the engineering requirements. Before the appearance of turbine engines, air cooled piston engines with radially-arranged cylinders were installed in helicopters. The high specific weight and dimensions, unevenness of torque moment, the necessity for installing a special fan with large air ducts for cooling the engine cylinders in the helicopter fuselage and a number of other deficiencies became the reason for turbine engines to be used in helicopters in place of piston engines.

Turbine engines possess lower specific weight and dimensions, have better vibration characteristics, operate on cheaper and less inflammable types of fuel and are simpler in operation than piston engines.

In the case of mechanical (transmission) main rotor drive in the helicopter, two-shaft (with a free turbine) turbine engines are primarily used.

In the two-shaft engine layout, differing from single-shaft engines, the turbine engine's power is transmitted to the main rotor through the free turbine which is not connected mechanically with the turbo-compressor part of the engine. The gas connection of the turbo-compressor part of the engine with the free turbine provides the possibility for changing the number of revolutions of the latter within a rather wide range with a constant rate of work of the turbo-compressor and decrease the power necessary to drive the main rotor. This allows the main rotor to be operated at a lower number of revolutions when hovering and at low airspeeds and to be operated at a higher number of revolutions while flying at maximum horizontal speed.

In connection with the fact that the free turbine of the engine is not mechanically connected with its turbo-compressor part, the necessity for a clutch is eliminated.

So that the number of revolutions of an autorotating main rotor is not brought down below that allowable when the helicopter is descending with the engine shut down, it is necessary to disconnect it from the free turbine. This is accomplished with a free-wheeling clutch which is installed between the main reduction gear and the free turbine.

For convenience in operation, the installation of a braking device is desirable for testing the operation of the turbo-compressor part of the engine with the rotor not turning.

If the purchaser has not indicated the engine, it is necessary to select the most applicable one from those existing or being developed.

Selection of Main and Tail Rotor Location

Location of the main rotors relative to the fuselage of a helicopter is determined with a selection diagram. So that the fuselage center line is aligned with the flight path during cruise flight, the main rotor shafts are not located perpendicular to the longitudinal axis of the fuselage, but are inclined forward by 5^{o} - 8^{o}.

The distance from the main rotor blades to the ground must be such that safety is provided for service personnel while the helicopter is standing at all possible working rates of the main rotor.

Location of the blades above the fuselage must be such that the danger of a blade striking any part of the helicopter is eliminated.

In helicopters with a lateral layout, the main rotors are located on one level. To decrease the dimensions and frontal resistance, overlapping of the rotors is used. The amount of overlap is determined after conducting special computations.

In longitudinally laid out helicopters, the rear rotor is installed higher than the front one to decrease the effect of the front one on it while flying horizontally.

Rotor overlapping is also used in this layout.

In helicopters with a coaxial layout, the distance between the main rotor hubs must be such that there will be no collision between the blades of these rotors under any conditions.

The tail rotor of a single-rotor helicopter equalizes the reactive torque moment of the main rotor and serves as a means of directional control.

The maximum thrust of the tail rotor while the helicopter is hovering must be no less than

$$T_{mr} = 1.25\frac{M_t}{L_{tr}}$$

where M_t -- maximum torque moment;

L_{tr} -- distance from the helicopter's center of gravity to the tail rotor axis of rotation.

So that the fuselage does not roll while hovering and in a vertical takeoff, the axis of rotation of the tail rotor must be in a plane which passes through the center of the main rotor bushing and perpendicular to the axis of the latter. Moving the tail rotor upward eliminates the danger of its blades striking on the ground, but at the same time requires that the spans of the tail boom be bent upward and an additional reduction gear be installed at the place where it is bent. This makes construction of the helicopter heavier and more complex.

Selection of Parameters for the Tail Empennage, Wing and Landing Gear

In helicopters with a single-rotor layout and having a tail rotor, only a horizontal empennage is used in the majority of cases, since the functions of the vertical stabilizer and rudder are fulfilled by the tail rotor. In some helicopter designs, a vertical stabilizer is installed to increase their directional stability. The horizontal empennage on a helicopter usually consists of one stabilizer.

To simplify control of the helicopter during flight with a horizontal speed, a change in the angle of stabilizer setting is kinematically connected with a change in collective pitch. The stabilizer allows the helicopter to be trimmed while transferring from one flight mode to another.

For helicopters of the two-rotor layout, both a horizontal and a vertical tail plane are required.

The parameters of the tail empennage -- area, angle of setting, distance from the helicopter's center of gravity and also its location relative to the main rotors and wing -- are determined after conducting corresponding calculations or are selected on the basis of analyzing statistics on similar helicopters.

Unloading main rotors with wings delays stalling in the main rotor blades. The following parameters of the wing are determined during design of the helicopter: area, span, taper, chord, angle of inclination and suction airfoil.

In a helicopter with a lateral layout, the wingspan is determined by the distance between the main rotor shafts, since the wing in this case fulfills the role of a beam for absorbing all forces and moments from the main rotor. Therefore, the wing must have sufficient rigidity against twisting and bending with the minimum possible weight. In

the hovering mode, the wing must have a minimal effect on the work of the main rotor.

In selecting wing parameters, designers are guided by aerodynamic, strength, economic and operational considerations.

Wheel shocks on the ground while the helicopter is being landed, and also shocks while moving the helicopter (takeoff run, rollout, taxiing and towing) along unevennesses in the parking area are absorbed by the gear oleos.

In selecting the layout and type of gear for the helicopter, designers are guided by the following:

1) Operational requirements;

2) Configuration of the helicopter;

3) Weight of the helicopter;

4) Aerodynamic requirements.

As a rule, nose wheel gear is used on helicopters. This is explained by the fact that this layout has a number of essential advantages by comparison with tail wheel gear (see page 84).

Preliminary Determination of the Weight of Helicopter Parts

Determination of the takeoff weight of a helicopter according to the coefficient of load ratio k is the first approximation and requires on a basis of treating statistical data of similar helicopters, the weight of the parts of a helicopter can be expressed in percentages of the takeoff weight of the craft, but in order to eliminate errors during this process, it is necessary to carefully analyze the basic parameters of single-type helicopters from the point of view of aerodynamics, construction and operations with considerations for characteristics of the power plants used.

The weight of finished products, including engines, electric and radio equipment, instruments, radiators, wheels and so forth is usually known and must only be checked.

When designing the helicopter, needed statistical data on certain assemblies may not be available. In this case, sketch plans of the assemblies are developed and their weight is determined after that.

After determining weight of the assemblies, a weight listing, which is necessary for arrangement of the helicopter and determining its center of gravity, is made up. The weight listing is composed according to groups. The more detailed the weight listing, the more accurate is the calculation of the helicopter's weight.

Helicopter Arrangement and Gravity Centering

The mutual space relationships between the parts of the helicopter, their form and the construction and load-bearing layout with placement of the crew, main cargoes, fittings and equipment with observance of a number of requirements of an engineering and operational order is called arrangement. (Fig. 135).

The arrangement of a helicopter depends on its layout, purpose, number and type of engines and many other factors. Besides this, the basic assemblies of a helicopter (power plant, transmission, main rotor, wing) are tied together and cannot be placed at will independently from each other. Therefore, satisfactory arrangement is not attained at once, but only by means of gradually approaching it.

During arrangement, the construction and load-bearing diagram is created, rational methods for transmitting forces from one assembly of the helicopter another are located, and also, layouts for the landing gear, placement of passengers, crew, radio equipment and other items, and also the transmission of forces from various cargoes to the construction elements of the assemblies are reviewed.

Arrangement is done with a longitudinal arrangement cutaway of the helicopter and separate lateral sections and cutaways. If the engines are located in separate gondolas outside the fuselage, there is also an arrangement drawing of a gondola. Arrangement cutaways are usually drawn to large scale (1 : 2, 1 : 5, 1: 10).

Arrangement is a complex creative process. During development of a helicopter's arrangement, it is necessary to have an installation drawing of the engine and drawings

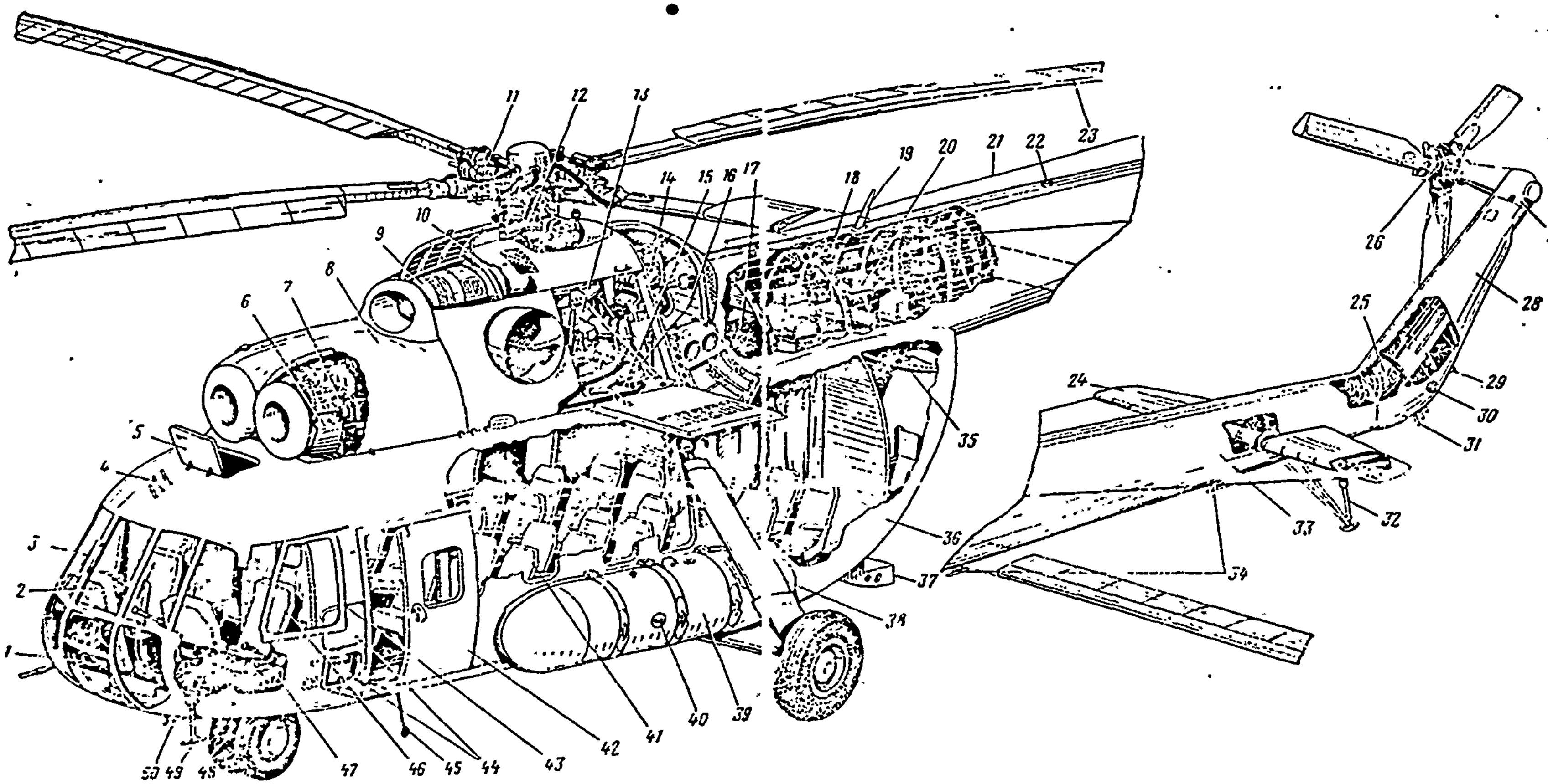

Fig. 135 Arrangement Diagram of a Passenger Helicopter:
Key on following page

Key for Fig. 135:

1) right foot control pedals, 2) right cyclic pitch control handle, 3) windshield wipers, 4) antenna, 5) engine access hatch cover, 6) oil tank, 7) engine, 8) cowling, 9) fan installation, 10) oil radiator, 11) main rotor hub, 12) rotor control assembly, 13) main reduction gear, 14) hydraulic panel, 15) control rods, 16) reduction gear subframe, 17) consumption fuel tank container, 18) tail shaft transmission, 19) command radio spike antenna, 20) radio equipment location compartment, 21) communications radio beam antenna, 22) flashing beacon, 23) main rotor blade, 24) stabilizer, 25) intermediate reduction gear, 26) tail rotor, 27) tail reduction gear, 28) end boom, 29) tail lamp, 30 and 31) antennas, 32) tail skid, 33) tail boom, 34) radio altimeter antenna, 35) upper flap of rear entry door, 36) fuselage center portion, 37) folding lower door, 38) gear main leg, 39) left external fuel tank, 40) position light, 41) passenger seat, 42) sliding entry door, 43) sliding blister, 44) niche for storage batteries, 45) communications radio trailing antenna, 46) left pilot's seat, 47) separate engine control levers, 48) nose gear, 49) pitot tube, 50) radio compass beam antenna

with indications of the dimensions of cargoes and special equipment with their centers of gravity marked on them.

The load-bearing elements of the fuselage are shown during placement of the power plant, wing, transmission and gear. The load-bearing frame is indicated on the arrangement drawing.

The minimum necessary volumes of framing construction are designed for the purpose of decreasing frontal resistance and the weight of construction.

The external outlines are placed on the arranging drawing. The arranging drawing, together with the overall view of the helicopter (in three projections) serves as the basis for making up theoretic drawings of the fuselage and its assembly with other parts of the helicopter.

The process of arranging is accompanied by determination of the helicopter's centering, which is to say calculation of the position of its center of gravity.

Centering is determined according to axes ox and oy (Fig. 136).

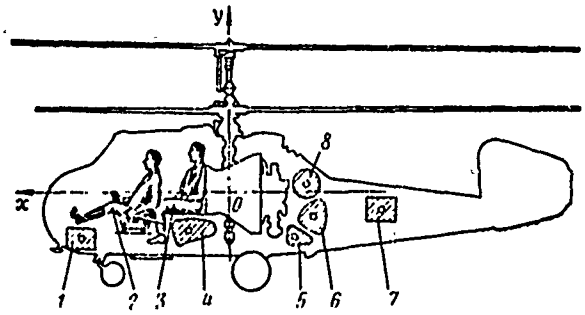

Fig. 136 Diagram of Coordinate Axes and Loading of a Helicopter:

Key: 1) storage battery, 2) pilot, 3) passenger, 4) front fuel tank, 5) antifreeze tank, 6) rear fuel tank, 7) storage battery, 8) oil tank

Axis oy usually runs tangential to the nose of the fuselage or near the suggested position of the center of gravity along the main rotor centerline.

Axis ox passes through any point located as low as possible on the drawing of the lateral projection of the helicopter.

Computation of the center of gravity necessarily precedes composition of the weight summary of list. The weight summary is made up on the basis of weight calculations conducted and lists on fittings, cargoes and so forth selected in correspondence with the requirements outlined for the helicopter. The list is made up in a definite order: first the composite parts of the helicopter's construction are noted, followed by notation of the main parts of the power plant, designations of fittings and so forth. Opposite eachdesignation, the corresponding weight is noted.

The weight list simultaneously serves as the balancing list, and therefore a graph of the centers of gravity for cargoes is located behind the weight graph and a graph of the static load moments is located behind it. The coordinates of the centers of gravity for cargoes are measured according to the arrangement drawing.

Calculations for the helicopter's balancing are conducted by the usual method of determining the center of parallel forces. The abscissa of the center of gravity from the origin of the coordinates is located according to the expression

$$x_{cg} = \frac{\sum Gx}{\sum G}$$

where Gx -- sum of the static moments of the cargoes;

x -- extended coordinate of the load center of gravity along the ox axis

The center of gravity ordinate is located according to the expression

$$y_{cg} = \frac{\sum Gy}{\sum G}$$

It is also convenient to express the balancing of the helicopter through angle φ_{cg}, which is formed by the main rotor center line and a line connecting the center of the hub with the center of gravity of the helicopter

$$\varphi_{cg} \simeq \frac{x_{cg}}{y_{cg}}$$

The balance is determined for all flying variations of the helicopter's loading and the foremost and rearmost positions of the center of gravity are determined.

The center of gravity of the fuel and payload must coincide with the center of gravity of the helicopter. The centers of gravity of loads in the fuselage and on external suspension must be located near the center of gravity of the helicopter.

The balancing obtained rarely coincides with that required, and it is therefore corrected by means of moving loads or moving the main rotor center line relative to the center of gravity.

After determining the basic dimensions and parameters of the helicopter and its parts, the overall view of the helicopter is drawn in three projections. In the process

of arranging and balancing, and also as the result of aerodynamic computations and computations on stability, necessary changes and additions are introduced into the overall view of the helicopter, after which the drawing of the overall view becomes one of the most important composite parts of the sketch plan.

The overall view allows the basic parameters and dimensions to be correlated and the external form of the helicopter to be established. The helicopter's overall view is required for preparation of drawings for models intended for aerodynamic testint (testing in a wind tunnel).

Three projections of the helicopter are given in the overall view drawing, the basic dimensions are established and a table containing geometric, aerodynamic and weight data and basic data on the engine is given.

Finalized execution of the sketch project for a helicopter contains the following technical documents:

1) Overall view of the helicopter in three projections (with the basic data table);

2) Arrangement drawing;

3) Preliminary assembly diagrams of the transmission and controls;

4) Weight and balance lists for required variations of loading;

5) Aerodynamic computations on the helicopter;

6) Computation on strength;

7) A short description of the construction.

A preliminary assembly diagram for the transmission is made up in order to ascertain the number and dimensions of reduction gears, clutches, the length of shafts and placement of shaft supports. A construction schematic and placement and angles of deflection of the rotor control assembly are given in the preliminary assembly diagram for the controls.

Aerodynamic calculations provide the answer to the question of whether or not the sketch plan satisfies the technical requirements in relation to assigned flying characteristics for helicopters.

An approximate calculation on strength is given for preliminary determination of the dimensions and weight of the basic load-bearing assemblies (the blades, hub and fuselage).

The scope and content of the sketch plan must be with sufficient initial material to develop the preliminary plan. The technical requirements must be fully satisfied in the sketch plan.

Chapter 4

Design of Parts and Their Connections Subjected to the Effect of Changing Loads

1. Ways of Providing Minimum Weight and Cost of Helicopter Construction Parts

As was shown earlier, one of the most important indices of a well-designed helicopter is its high flying and engineering data and reliability and economy in operation. This means that the design of the helicopter must be light and strong, easily engineered and cheap in production, have a large margin of strength and be convenient for work of the helicopter's servicing personnel.

All this must be considered while designing the separate parts, components and assemblies of the helicopter.

The weight of the helicopter's construction has great significance. This can be judged according to the coefficient of load ratio $\bar{K}$ of the helicopter. The higher $\bar{K}$, the more successfully the helicopter is designed from the point of view of its construction, the lighter its construction at a given takeoff weight, and full loading is greater, allowing a greater payload or longer range.

The minimum weight for the design can be attained if the minimum weight is achieved for each of its composite parts -- assemblies, parts and components.

In decreasing the weight of the design, the designer also decreases the cost of the helicopter.

However, decreasing the weight of the design must not lead to a decrease in its strength and consequent decrease in reliability.

The achievement of engineering effectiveness in the design means the achievement of lowering its cost in production by means of attaining high production indices, a high degree of automation and mechanization in production and machining of parts and decreasing periods required for mastering production.

High engineering effectiveness is basically attained with the following measures:

a) Unit construction on compartments and panels, allowing labor consuming operations to be mechanized, labor productivity to be increased and product quality to be improved;

b) Giving the parts forms which allow highly productive processes -- pressing, stamping, welding and so forth;

c) Widespread usage of standardized and stock parts and parts and assemblies which have been mastered previously;

d) Proper designation of manufacturing precision and part surface fineness.

The convenience requirement for work by the helicopter's servicing personnel indicates the necessity for providing the specialists with free access for inspection, assembly and disassembly of the assemblies installed in the helicopter and also access for conducting adjusting operations outlined in the operating instructions

High reserve in the helicopter's design testifies to the fact that the helicopter will be operational for an extended period of time without major overhaul or replacement of assemblies. The high reserve is closely tied with strength in all components, parts and assemblies of the helicopter.

Selection of Material

When designing parts and components, strength calculations are conducted by the normal method of consecutive approximations. Preliminary calculations are first performed according to the assigned technical conditions, and then the basic dimensions of the parts are determined. The sketch drawing of the part or component is made up according to the data received. During this, the dimensions selected are rounded off and changed according to construction considerations, standards and norms. After this, checking computations are made to determine coefficients of strength reserve in the most stressed parts of the component.

The strength reserve η of any element of construction is the relationship between the destruction stress and the stress arising due to the action of calculated loads

$$\eta = \frac{\sigma_d}{\sigma_{calc}}.$$

After evaluating the computed coefficients of strength reserve, corresponding changes and corrections are made in the drawings and checking calculations are made again. Immediate determination of parts dimensions according to set allowable stresses is possible only in the simplest cases.

Evaluation of the coefficient strength reserve and the selection of allowable stresses must be decided in the process of designing the helicopter with considerations for the engineering and economic indices.

The coefficient of strength reserve must present a representation on the degree of reliability of the construction under possible deviations from design conditions (occasional loads, unexpected increase in the number of revolutions, change in the temperature rate, and also phenomena connected with oscillations, wear, corrosion and so forth).

In the determination of parts strength, the selection of material has great significance and is decided in the process of the sketch planning.

The selected material must possess:

1) High strength and low specific weight;

2) Stability of mechanical properties and weight in time and under the effect of the surrounding medium;

3) Necessary fatique strength and flexibility;

4) Maximum possible resistance against corrosion;

5) Properties allowing progressive processes to be used during its machining (pressing, stamping, welding, rolling, casting and so forth).

Determination of the weight utility of one material or another for a given part is not always very simple. It is impossible to establish any sort of overall criterion of weight utility for a material which is to be used for any case which can be encountered in construction of a part.

Criteria of weight utility will differ depending on the type of part loading under tension, compression, torsion and so forth. The problem of weight utility of a material is somewhat more simply solved for heavily loaded parts when they are working on tension or pure compression

(without the loss of total or localized loss in strength).

The weight and strength of a construction part are interconnected, and therefore materials should be compared with consideration being given to both factors simultaneously. For this, the understanding of specific strength of the material is introduced, and is understood to mean the relationship of the strength characteristic to its specific weight.

The basic formulae for determining the specific strength of materials are:

$\frac{\sigma_{tr}}{\gamma}$ — under tension; $\frac{\sigma_{co}}{\gamma}$ — under compression,

$\frac{\tau_{sh}}{\gamma}$ — under shear; $\frac{\sigma_b^{\frac{2}{3}}}{\gamma}$ — under bending; $\frac{\tau_{tr}^{\frac{2}{3}}}{\gamma}$ — under torsion; $\frac{E^{\frac{1}{2}}}{\gamma}$ — under longitudinal bending.

When these formulae are used, it is necessary to consider conditions of geometric similarity of cross sections and the possibility of strength loss.

In some cases, the question of material is decided most correctly of all on the basis of comparative computations of the number of cross sections of each part. The parts in a construction can be weakly loaded even with a wisely developed load-bearing schematic.

In this case, a striving to obtain calculated stresses in their sections will lead to a sitaution in which the dimensions of the sections will turn out too small and inadmissible from the point of view of engineering their production and machining. In these cases, materials with the lowest possible specific weight should be used.

Equal Strength in the Parts of a Construction

Equal strength in a construction takes place whm under destruction loading, the destruction stresses act in all sections of the part. In the majority of cases, the precise execution of this condition is impossible to realize. However, the designers' task includes selection of such a form for the part that the equal strength condition is answered to a large degree if there are no special requirements stipulated for rigidity of the construction.

Parts Sectioned Form in a Construction

With identical strength in parts, a decrease in weight can be achieved by giving a different form to their sections.

The question of section form is connected not only with provisions for the parts strength but also with an increase of their overall and localized stability.

The maximum overall position is formulated in the following manner. The section form of parts (Fig. 137) must be such that the main part of the material is concentrated in their most highly stressed zones. The configuration of parts must provide absorption of loads with minimum possible stresses. Transmission of loads to other parts is necessary in the most expedient location and direction.

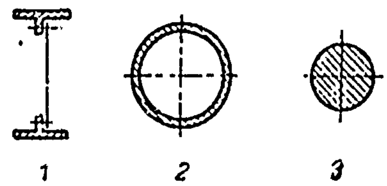

Fig.137 Workable Parts Section for Various Types of Deformation:

Key: 1) under bending, 2) under torsion, 3) under tension (compression)

Under bending, it is wise to displace the mass of the material away from the neutral axis to increase the moment of resistance, and the load on the part must be absorbed in the center of rigidity of the section in the plane of bending.

A point on the cross section of a uniform beam is called the center of rigidity of the section if it transfers force applied to it or passing through it causes bending without torsion. The center of rigidity always lies on the axis of symmetry of the section. If the section is symmetrical relative to two or more axes, the center of gravity coincides with the center of rigidity (which is also the center of symmetry). For asymmetrical constructions,

the center of rigidity of the section is sometimes determined as the "center of gravity" of the inertia moments of the parts section which absorb normal stresses. The center of rigidity is more correctly determined with calculation of the distribution of tangential forces along the contour.

Under torsion, a section having a closed contour with a large perimeter and equal distribution of the material around the contour is most usable.

Under tension and compression, symmetrical sections with the material concentrated along the line of action of the force is most applicable.

Sections of construction parts which work under longitudinal bending will be most usable if the material is displaced from the neutral axis so that the allowable critical stresses of overall and localized stability are the same. For instance, a galvanized tube will increase the local rigidity of a shell and allow the range of their usage to be broadened.

Forces and moments must be absorbed in the place where they arise and must be transmitted across the shortest possible distance.

Calculation of the Power Flow when the Parts are Engaged in Work

The distribution of power flow is similar to the distribution of hydraulic flow. With an improperly selected parts form, "stagnant" zones in which there is no power flow are possible. Material in these zones does not work and it is necessary to remove it. Fig. 138 shows examples where the zones of parts in which the material doesnot participate in absorbing loads and must be eliminated is shown by cross hatching.

However, it is necessary to design parts and components in such a manner that there are no sharp changes in rigidity in the construction and the butts of the load-bearing parts are located in the places of the least resistance. For instance, if under conditions of strength and rigidity, not all stringers are required to be placed along the whole wing, the stringers must be cut off at corresponding ribs.

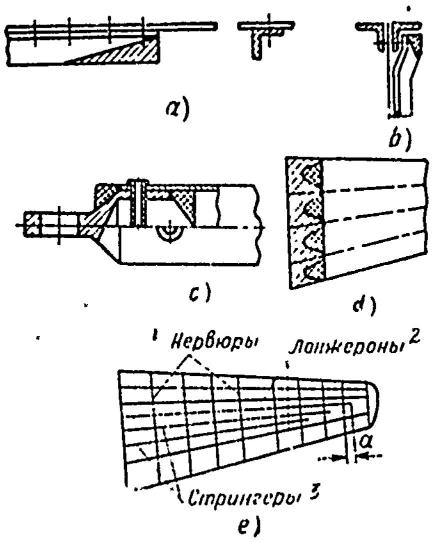

Fig. 138 The Effect of Power Flow Along the Sections of a Part on its Form:

Key: a) rib end, b) spar brace and c) rod end, d) skin fastening on butt of fuselage parts, e) longitudinal load-bearing set of wing, 1) ribs, 2) spars, 3) stringers

Value a (approximately 15 - 20 mm) is the engineering surplace of the stringer beyond the rib (see Fig. 138 e).

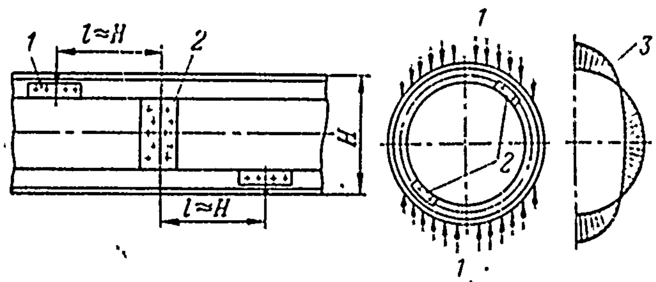

Fig. 139 Diagram of Butt Location:

Key: a) two-band spar: 1) band butt, 2) wall butt, b) normal frame: 1) load, 2) butt, 3) bending moment diagram

When butt-joining long constructions of the wing spar type, it is expedient to displace the butt joints of the several parts making up the spar (Fig. 139 a). It is expedient to place the butt joints in the least stressed positions (see Fig. 139 b).

Section 2

Design and Engineering Factors Affecting Fatigue Strength of Parts

Basic Concepts

Oscillations (vibrations) in assemblies and the consequences connected with them have an essential meaning in helicopter construction. There are constant sources of forced and spontaneous oscillations on a helicopter -- the main and tail rotors and the components of the helicopter blown by them (fuselage, stabilizer, wing and so forth).

The changing forces cause oscillations of the same frequency. In case this frequency coincides with the natural frequency, resonance will ensue and the oscillation will become intensive.

With significant oscillations in assemblies in the construction, large changing stresses will arise and can lead to its destruction. This type of destruction usually occurs ounexpectedly, since it is not preceded by any sort of signal concerning the onset of danger.

A reason for destruction of the construction can be fatiguing of the material or insufficient fatigue strength of certain of its parts, which is usually characterized by the number of cycles N which it can sustain before failing at a given amplitude of changing stresses σ. The larger the amplitude of changing stresses σ, the lower the number of stress cycles which the construction can sustain.

The largest amplitude of stresses under which the construction can sustain any high number of loading cycles N without destruction is called the fatigue limit σ_a.

The curve characterizing the number of cycles N before destruction depending on the amplitude of changing stresses σ is shown in Fig. 140a. At stresses less than $\sigma_{a_{min}}$, which is called the minimum fatigue limit, not

sample fails, even under a very high number of loading cycles The value of the amplitude of changing stresses under which the construction can sustain a given number of loading cycles N before destruction depends on the value of the constant portion of the cyclic stress σ_m (static loading). The larger σ_m, the smaller the amplitude of stress under which the construction can sustain a given number of cycles (see Fig. 140b).

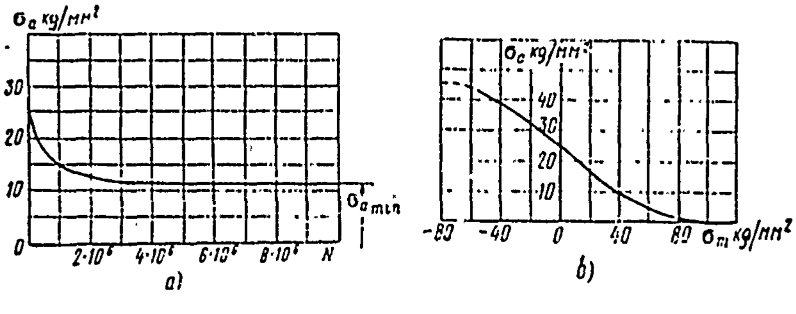

Fig. 140 Dependency Curve of the Number of Cycles on the Amplitude of Changing Stress (a) and Dependency Curve on the Constant Portion of Stress on the Value of Changing Stress Amplitude (b)

In regions of constant compression stressing, the fatigue limits essentially increase. This condition is taken advantage of when strengthening construction parts by riveting.

The safety margin of the construction is usually established on the basis of results of its dynamic testing, with testing being sometimes conducted on several examples for final evaluation of the construction's reliability. Often, only certain parts of the construction are subjected to testing and their strength is the determinant for the entire tested assembly as a whole. Thus, when determining the strength margin of a main rotor blade, testing is conducted on samples of certain spar sections having framing parts which create stress concentrators in the spar. Samples of no less than three different sections of the spar, for instance, the section including the root joint and two sections of the spar having the most dynamic stresses, are tested.

Testing of the blade as a whole and not separate short samples of it is not, as a rule, conducted in view of the excessively great complexity of stands which would be required for this.

To achieve a high strength margin in helicopter parts and components which work under conditions of dynamic loading, their design must be carried out with careful calculation of fatigue strength requirements. For solving this vital problem, it is necessary to have a deep understanding of the physics of phenomena connected with fatigue failures, know the reasons for the appearance of these types of destruction and be able to use corresponding methods to increase the fatigue strength for an actual design decision.

One of the reasons for appearance and growth of fatigue cracks in parts is the presence of small zones in which inner forces arise which are significantly more intensive than in the basic mass of the material of the part. Primary causes which interrupt the smoothness of internal force distribution in parts are concentrators (sharp changes in section, hollow champfers, projections, holes, openings, slots and keyways, scratches remaining after machining and so forth).

Stresses arising in the area of the concentrator are called local stresses.

Local stresses arising in the region of load-bearing concentrators (in the areas of fit) are called stress concentrators.

Achieving a high value in the immediate proximity of the concentrator, local stresses diminish very rapidly according to distance from it. Local stresses basically depend on the geometry of the concentrator, for instance, the radius of fillet rounding. They may arise near natural concentrators (internal microcracks, impurities, irregularities in the structure of the crystal grid) and near load-bearing concentrators.

A fatigue crack begins to be formed in zones of stress concentration.

A local zone of plastic deformation is formed in the region of the concentrator at the same time that the basic mass of the part's material is still located in the zone of flexible deformation. In connection with this, some redistribution (equalization) of local stresses takes place. The more plastic material, the more stress redistribution is noted. This is explained by the fact that the greater the plasticity of their material, the less the effect of local stresses on the part's strength.

When evaluating fatigue strength of spars, special attention should be paid to the possibility of the appearance of friction corrosion. Friction corrosion is an almost unavoidable byproduct of cyclic loading in blades and will lead to an essential decrease in fatigue strength. It usually arises in points of contact between the spar and parts fastened to it if there are relative micromovements between the parts and the spar.

Fatigue strength in axles and shafts is decreased if bushings, bearing races and hubs are pressed onto them. The presence of a fit decreases the fatigue strength of a shaft with a part pressed on it by comparison with the fatigue strength of a free shaft. This is explained with three reasons: stress concentration as the result of the fit, contact friction, arising under changing stresses between parts which are assembled with an interference, and the effect of corrosion.

Contact friction under changing stresses will lead to wear of the fitting surface of the shaft, as a result of which the exposed portion of the metal may be exposed to the effects of moisture and chemically active substances.

Nicks on the surface of the shaft which arise when a bushing is pressed on in a cold condition can be the cause of a significant decrease in fatigue strength.

The reliability of assemblies in operating conditions depends to a significant degree on the fatigue strength of their parts. Testing for fatigue and observing the behavior of parts under working conditions will reveal the effect of form, dimensions and surface conditions of material layers on strength and longevity of the parts.

Up to the present time, the actual ways of increasing strength and lengthening service life of parts by means of bringing design, engineering, metallurgical, operational and preventive measures into play have been set.

Design measures include giving the parts a form which will enable a wise and most equal possible distribution of internal forces.

Engineering measures include: careful machining of parts surfaces; anticorrosion coverings; creation of residual stresses in the parts which, in conjunction with the working stresses, would provide favorable working conditions of the part (unloading the more highly stressed and loading the less stressed parts of the construction).

Metallurgical measures include the most successful selection of material and establishment of the optimum rate of heat treatment, and also struggling against the appearance of shrinkage hollows and cracks, gas bubbles and impurities. Cementation, nitriting and cyaniding surface layers of the material can be included here.

The strength of a blade spar can be essentially decreased if various engineering defects are permitted during manufacture of the spar. We will look at the most dangerous of these.

In the process of hot rolling a material, plastic deformations can be accompanied by its partial destruction. This usually occurs at a low temperature of the rolled stock, and also as the result of the material's becoming soiled with nonmetallic and gas impurities, high porousity and other metallurgical defects. Destruction of the material is not eliminated during further cold rolling, and the rolled film of metal is drawn out.

Large unevennesses in the external surface take place after hot rolling. Consequent plastic cold drawing will lead to uneven movement of the material, during which defects called laps can be formed.

After hot rolling, a layer of scale which is harder than the metal remains on the surface of the tube. If this scale is not fully removed, it is crushed and pressed into the metal during rolling, forming a so-called "rash".

Longitudinal grinding of the external and internal surfaces of the tube after completion of cold rolling is very effective in eliminating these and other surface defects.

After annealing and tempering the spar tube, several distortions are present and must be corrected before assembly. During this, residual stresses which will lead to a decrease in fatigue strength are created in the tubing material.

In order to eliminate the necessity for correction, tempering of annealed tubes should be done in special devices which eliminate deformations arising during the process of annealing.

The internal canal of a duralumin spar is often not machined after pressing, and therefore defects from the pressing process -- caking, longitudinal scratches, gas bubbles and so forth -- can remain on the inner surface.

These defects can also decrease the fatigue strength of the spar. Consequently, the internal surface of blade spars must necessarily be subjected to machining after pressing.

To discover nonmetallic and gas impurities, each spar must necessarily be subjected to ultrasonic testing.

Operational measures must include measures for protecting the parts from corrosion (paint, lubricant coating); protecting stressed and vital parts from damage (nicks and dents during assembly and disassembly, file marks); protecting working surfaces from becoming soiled and the appearance of increased wear, scoring and similar phenomena associated with this. In blade constructions in which the spar is a steel tube, the spar is usually fully protected by a frame and cannot be mechanically damaged in operation. Corrosion represents the most dangerous thing for this type of construction and therefore, the period of service for these blades is determined by the quality of anticorrosion covering of the spar.

For blade constructions in which the spar forms the contour of the leading portion of the airfoil, special attention must be paid to its protection from mechanical damage. In this case, the spar strength reserve is dependent on the amount of damage inflicted on it. It is also necessary to take measures to protect the spar from the abrasive action of the surrounding medium.

We will look at the basic measures which the designer can use to effect increased fatigue strength in parts.

Design Measures

The most widely used measures for increasing fatigue strength of parts which are used by designers in their constructions are:

1) Increasing the area of a dangerous section and changing its geometry;

2) Decreasing stress concentration;

3) Changing rigidity.

A helicopter blade works under trying conditions. Over the course of its entire life, it experiences constant and changing loads which are very high in value. This peculiarity in the working conditions of a blade necessitates extremely rigid requirements for its construction and, first of all, for fatigue strength of its main load-bearing element -- the spar. Therefore, a blade spar must be manufactured only of materials possessing very high characteristics of fatigue strength.

The most important requirement for blades with steel and duralumin spars is elimination of stress concentrators. In blade construction, the use of bolted or riveted fastenings are inadmissible and the blade framing must be fastened to the spar only by bonding.

The use of bolted or riveted fastenings is allowed only in sections with small changing stresses, for instance, at the blade root near the hub hinges. In this, regardless of the load changing stresses, the spar section in the area of the butt joint must be increased by several times.

An increase in the area of the critical section allows fatigue strength of the part to be increased but will lead to an increase in the weight of the part. For instance, a shaft, working under conditions of dynamic loads, is weakened by the hole for lubricant feeding to the bearings (Fig. 141). In this case, to strengthen the shaft, its internal boring must be made in a form so that it has an increased section area in the places where the holes are located regardless of the fact that the measures complicate manufacture of the shaft and will lead to an increase in its weight.

When designing shafts which work under torsion and bending, it is considered that the main stress concentrators are fillets, splines, edges of parts pressed onto the shaft (bushings, bearing races and so forth) and holes.

A welded connection does not allow great dynamic loads and affects the strength reserve of the entire part to a significantdegree. For instance, a blade control arm (Fig. 142) is formed out of two parts by welding. Under dynamic testing of this linkage, it was established that destruction of a fatigue nature began on the outer side along the edge of the welded seam in the place of transfer from a smaller tube section to a larger one.

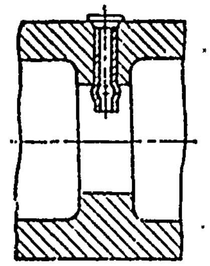

Fig. 141 Strengthening a Shaft at the Point of Hole Location

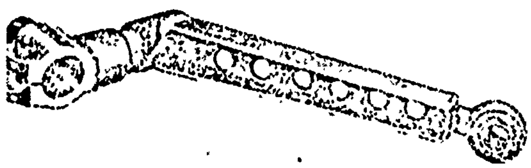

Fig. 142 Blade Linkage after Dynamic Testing. Destruction occurred at the point where the two parts were welded.

A hole for tubular riveting (Fig. 143) in which the flash was not removed along the edge on its inner side serves as the origin of failure in a rod.

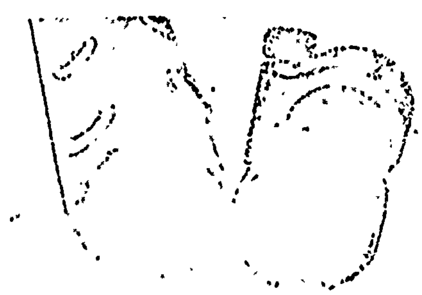

Fig. 143 A Rod after Dynamic Testing. The destruction occurred at the hole for tubular riveting.

Destruction of a shaft journal (Fig. 144a) began in a place where the control linkage connecting the rod with the rotor control assembly was seated. Spreading of the crack (see Fig. 144b) took place along a spiral line (along the smooth surface) on which significant hammering and friction corrosion took place in the form of powdered metal oxide. Besides this, destruction of the material (see Fig. 144c) occurred in the section of maximum corrosion. The for mation of friction corrosion is the major reason for a decrease in fatigue strength of the shaft journal.

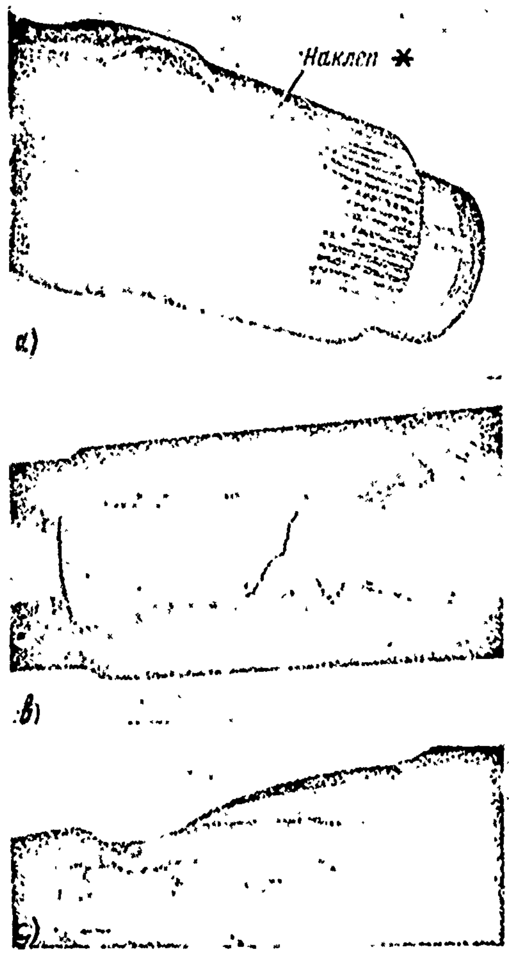

Fig. 144 Control Shaft Journal after Dynamic Testing. Destruction took place at the location of linkage seating.

Key: a) overall view of destruction (site of hammering is visible); b) spread of fatigue crack, c) section of maximum friction corrosion (magnified), *) hammering

Destruction of a universal joint yoke (Fig. 145 a) occurred along the conic portion and began from the hole. The destruction bears a fatigue character. The beginning of the appearance of the fatigue crack coincides with a non-circular point in the transfer from the cylindrical portion of the hole to the conic one. Fig. 145 b shows destruction of a universal joint yoke due to poor quality machining of its inside surface.

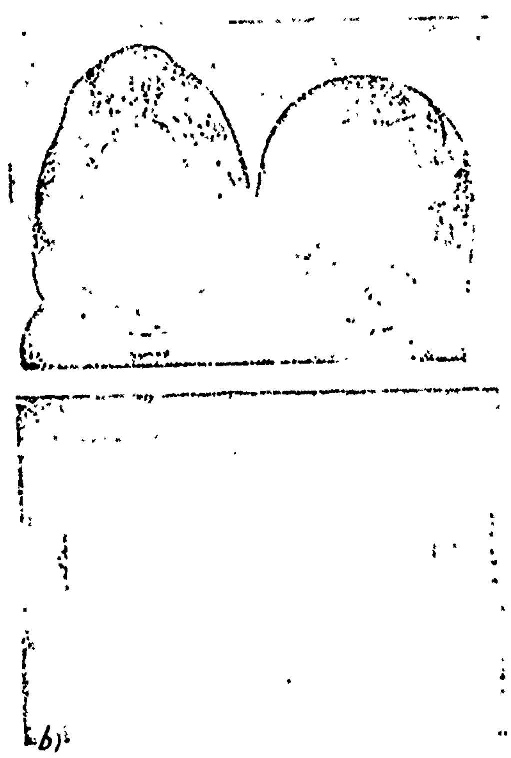

Fig. 145 Universal Joint Yoke after Dynamic Testing:

Key: 1) overall view of destruction, b) internal surface of yoke (traces of poor quality machining are evident)

Destruction of a rod occurred along its tip connector (Fig. 146). The fatigue crack appeared simultaneously in two places and carried its beginning along the inner threads of the connecting tip.

The outer ring of a rotor control assembly made of AK 6 material fails under dynamic testing (Fig. 147). Destruction occurred along the radius of the transfer from a flat to the cylindrical portion of the ring. A tiny porous place discovered in the break served as the origin of destruction.

Fig. 146 Destruction of a Rod after Dynamic Testing. The fatigue crack appeared in two points (a and b) and the origin is carried along the entire thread of the connecting tip.

Fig. 147 Rotor Control Assembly Ring after Dynamic Testing. A tiny porous place served as the origin of stress concentration.
1) beginning of break.

The amount of local stress depends on the geometry of the concentrator.

Fig. 148, 1 presents three groove shapes on the surface of a shaft. All grooves have equal depth t and entry radius r, while exit radius R differs. Local stresses in shafts having similar groove forms differ very little.

The basic factor on which the amount of stresses in the area of fillets depends is the radius of curvature r. With an increase in the radius of curvature, stress concentration is decreased to a significant degree. However, in certain constructions it is not possible to increase the radius of curvature. Thus, Fig. 148, 2 shows a shaft whose fillet radius is increased due to race A. In the absence of such a race, fillet radius r would have to be made less than radius r_1 on the face portion of the bearing race.

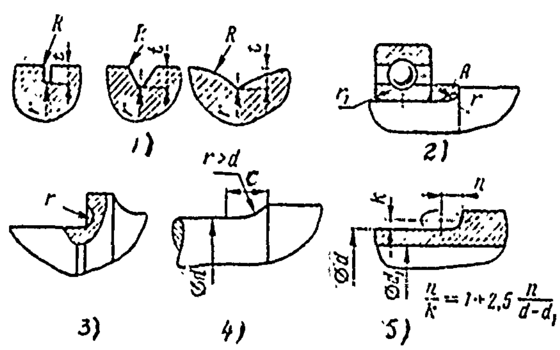

Fig. 148 Methods of Decreasing Stress Concentration by Changing Shaft Diameter:

Key: 1) effect of groove form on local stress, 2) intermediate ring A for increasing fillet radius, 3) fillet with undercut, 4) fillet with large radius of curvature, 5) elliptical fillet on hollow shaft, t) depth of groove, r) entry radius, R) exit radius, r_1) radius of curvature of bearing race, c) length of transfer portion, d) external shaft diameter, d_1) internal shaft diameter, n and k) ellipse axes

Fig. 148, 3 shows a method of decreasing stress concentration by means of forming a circumference which goes into the shaft projection (fillet with undercut).

Fig. 148, 4 shows a smooth transfer from a lesser diameter to a larger one. A similar method of assembling two parts of a shaft almost totally eliminates concentration of stresses, but they are often not feasible design-wise since in this case the length of the transfer section c turns out to be very large.

A transfer with a gradual decrease in fillet curvature radius (elliptical fillet) gives good results. Fig. 148, 5 shows the optimum relationship between the axes of the ellipse formed and the dimensi ns of the shaft. If dimension n must be as small as possible ($n \leq 0.1$ d) for design considerations, a normal circular fillet is used, since it is difficult to give the desired form to a circumference on a length less than 0.1 d in practice. If the transfer is smooth enough so that n is greater than or equal to d, then concentration of stress can be considered to be absent for practically any shape of the curve forming the fillet.

The slight advantages of the elliptical fillet and the engineering difficulties associated with its execution allow this transfer to be used only in especially vital constructions.

The most stresses arise where rigidity in the elements of construction undergoes sharp changes. Thus, for instance, shaft part A is less rigid than part B (Fig. 149, a). Decreasing the rigidity of part B and consequently equalizing the stresses to some degree, can be achieved by means of forming relieving grooves 1. Relieving grooves are used in cases where it is impossible to increase fillet radius r to a sufficient degree because of design considerations.

Fig. 149, b shows the usual construction of a shaft in the place where a bearing is fit on it and an improved construction using a fillet with undercut 5 and relieving groove 4.

The fatigue strength of shafts with fillets is increased by means of shot blasting or by turning the fillet with rollers. Strength during shot blasting is sometimes increased even in a case where the form and dimensions of the concentrator do not allow the shot to penetrate into the depth of the groove.

Grinding rolled or shot treated parts can give good results in cases where the layer removed during the grinding is extremely small.

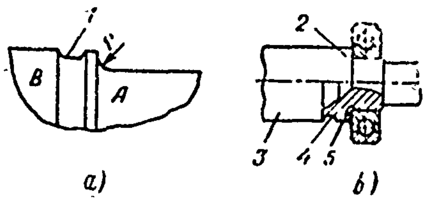

Fig. 149 Method of Decreasing Stress Concentration in Places where Construction Elements Undergo Sharp Changes in Rigidity:

Key: a) decreasing local stresses with a relieving groove; 1) relieving groove; r) fillet radius; b) normal (2) construction of a shaft in a place where a bearing is pressed on and improved (3) construction (fillet with under cut 5 and relieving groove 4)

Fig. 150, a shows a section of a shaft with a keyway. Local stresses depend to a large degree on the value of radius of curvature r.

In shafts working under changing loads, the entry angles of the keyway must be rounded off.

The keyway (see Fig. 150, b) is obtained by means of longitudinal milling (cutter of radius R), and from the point of view of distrubiting stresses in the area of the keyway end, should be considered more wise than the key-way (see Fig. 150, c) obtained by means of milling with an end cutter (entry radius r).

Fig. 150, d shows an unsuccessful combination of keyway and fillet which led to the formation of fatigue crack A. A splined connection is more sensible than a keyed one and must be used in all vital connections. The form of the splines (Fig. 151, a) affects the strength of the splined connection. The maximum increase in local stresses takes place with right angle splines. The basic reason for this sharp increase in local stresses is the small radius of transfer in the splined grooves. A splined connection in which the splines are made evolute with an angle of engagement $\alpha = 30^{\circ}$ and the grooves drawn along a radius has a stress concentration which is half as large.

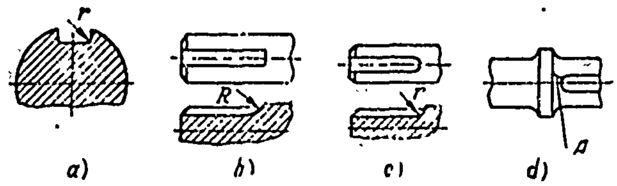

Fig. 150 Methods of Decreasing Stress Concentration in the Presence of a Keyway on a Shaft:

Key: a) keyway on a shaft, r) entry radius, b) keyway obtained by means of longitudinal milling, R) cutter radius, c) keyway obtained by milling with an end cutter, d) unsuccessful combination of keyway and fillet, A) fatigue crack

Tests for fatigue showed that the shaft (see Fig. 151, b) in which the diameter of the spline grooves is less than the diameter of the shaft is weaker than a shaft in which the diameter of the spline grooves is equal to or greater than the diameter of the shaft. This is explained by the fact that in the second case, stress concentration at the point of transfer from the splines to the shaft is almost absent. Underconditions of the proper selection of dimension d and d_1, equal strength of the shaft is provided in sections both close to the splines and removed from them.

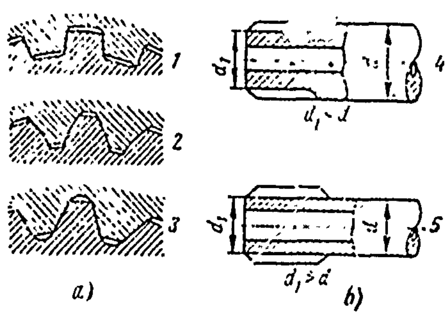

Fig. 151 Methods of Decreasing Stress Concentration in Splined Connections:

Key: a) spline shapes, 1) right angle splines, 2) splines with engagement $\alpha = 20°$ and small radius of transfer in grooves, 3) splines with engagement angle $\alpha = 30°$ and splines drawn along a radius, b) transfer from splines to shaft, 4) diameter of spline grooves less than diameter of shaft ($d_1 < d$), 5) diameter of spline grooves equal to or greater than shaft diameter ($d_1 \geqslant d$)

The failure of a splined connection can occur due to the hammering. The presence of hammering in splines testifies to the poor splined connection, which leads to an uneven distribution of loads on the splines.

Strength of threads depends on the evenness of force distribution among the thread turns.

The shape and height of the nut affects the distribution of loads along the thread turns. With a standard nut construction, the lower turns are most loaded. An example distribution of loads along the turns of a nut is shown in Fig, 152, a. An increase in nut height does not essentially affect the loading of the lower turns, and in this case the upper turns are insignificantly loaded. Fig. 152, b shows a nut shape which provided more equal distribution of the load on the thread turns. In order to ease the work of the lower turns, nuts with sunken threads are used. In this construction, some additional yielding of the lower turn is provided. Conic counterboring of the threads is also used to decrease loading on the lower turns. In a number of vital connections, the standards and norms for nuts are rejected. Thus, for instance, it is possible to make the loading along the turns more equal if one goes from a normal compression nut to a tension or tension-compression one.

A tension nut provides better distribution along the thread turns than does a compression one. The introduction of cones on the nut or simultaneously on the nut and on the bolt end promotes further strengthening of the connection. The latter construction provides a more even distribution of load, however, it is technologically more complex than others.

The use of tension-compression nuts provides the possibility for equally loading the turns of a thread due to the fact that the force on the nut thread is transferred to the projection located in the middle portion of the nut.

The proper selection of the fillet radius will lead to a strengthening of the threaded connection. To increase strength, the preferred bolts and stud have a shaft diameter equal to 0.85 - 1.0 times the internal diameter of the thread, since this makes them equally strong and less rigid. (See Fig. 152, c).

In designing special bolts and studs, it is necessary to pay attention to the place where the bolt head is assembled with the shaft and also the shaft of the threaded section. It is recommended that radius of curvature r at

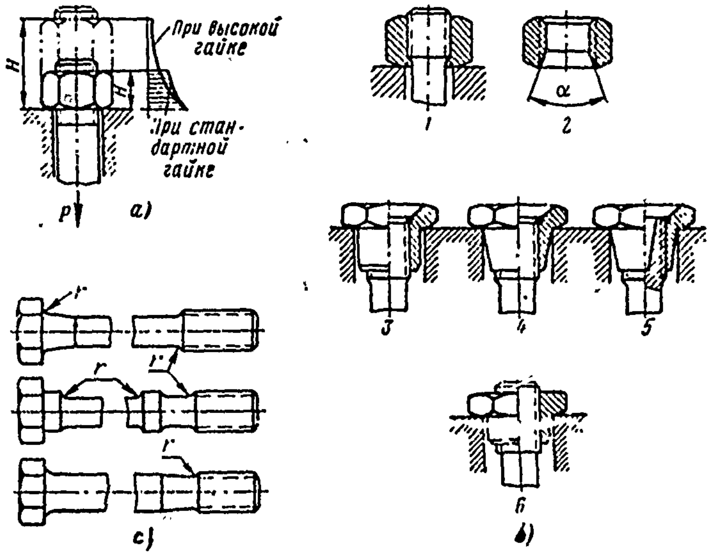

Fig. 152 Methods of Decreasing Stress Concentration in Threaded Connections:

Key: a) effect of nut height H on distribution of load across the thread, b) shape of nut providing more equal distribution of load on the thread turns, 1) nut with sunken thread, 2) nut with conic counterbored thread, 3) tension nut, 4) conic tension nut, 5) conic tension nut and cone on bolt end, 6) tension-compression nut, α) angle of counterbore, c) shape of transfer from shafts to head, collars and threaded part of bolt, r) fillet radius

the junction between the shaft and the threaded section be made

$$r \geqslant 0.2d$$

where d -- external diameter of the thread.

It is recommended that radius of curvature r in places where the bolt shafts transfers to the centering band be made

$$r \geqslant 0.5d$$

Small radii of curvature provide high stress concentration. Fillets composed of two arcs,elliptical fillets of fillets with conic sections affect bolt strength favorably.

Concentration of stress essentially depends on the radius of curvature in the thread grooves. An increase in the radius of curvature from r = 0.1s to r = 0.2s (where s -- thread pitch) provides an increase in fatigue strength by 100%.

A normal metric thread, allowing a radius of curvature r = 0.108s, is in many cases insufficiently strong for vital threaded connections. In these cases, a thread with r = (0.15 - 0.2)s is used. Radius of curvature r greater than (0.2 - 0.25)s are unusable since the degree of overlapping turns of the nut and bolt is decreased and the distribution of load among the turns is worsened due to the lower yielding of the turn.

An increase in the strength of threaded connections work under changing loads can be achieved by rolling the thread base on rollers in places of stress concentration. The rolling of small diameter threads is especially favorable. Heat treating after manufacture of threads is always unfavorable (especially after rolling). When rolling with rollers, residual compression stresses arise which are favorable for increasing fatigue strength.

Stress concentrations arise near corners A of bushings seated on a shaft. Besides this, with repeated bending of the shaft, the corners of the bushing grind the shaft surface. All this can be a reason for the appearance of fatigue cracks. To eliminate the grinding and increase the strength of the shaft, its diameter should be somewhat increased at the place where the bushing is pressed on (see Fig. 153, b). It is, however, necessary to remember that local stresses in turn arise in the transfers (points B).

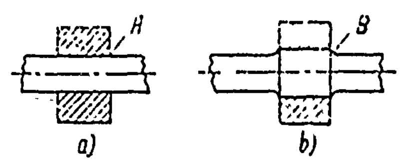

Fig. 153 Methods of Decreasing Contact Stresses

Key: a) shaft and bushing pressed on it, b) shaft thickened in the place where the bushing seats on it

Breakage in gear teeth and splines often occurs due to cracks which get started at the base of the teeth where stress concentration occurs (Fig. 154, a). The stress peaks near the roots of the teeth can be decreased by means of decreasing the rigidity of the gear by turning grooves (see Fig. 154, b). The groove (see Fig. 154, c) simultaneously eases concentration of stresses at the transfer points from the shaft to the gear and near the teeth roots.

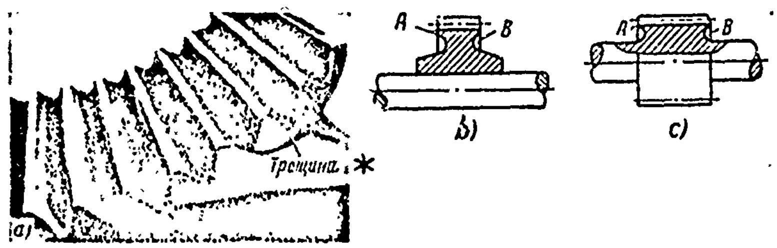

Fig. 154 Methods of Decreasing Stress Concentration in Gear Teeth Roots:

Key: a) destruction of gear after dynamic testing. Fatigue crack begins at the base of the gear tooth; b) decreasing stress concentration at teeth roots by means of decreasing gear rigidity: A) possible site of fatigue crack appearance, B) groove for decreasing stress concentration, c) decreasing stress concentration near teeth roots and at point of transfer from shaft to gear, * crack

Parts in the main rotor hub of heavy helicopters have relatively low rigidity. It is necessary to take special measures providing the equal distribution of loads in the needle bearings of the horizontal and vertical hinges. Satisfactory distribution of loads along the length of the needle bearings of the horizontal and vertical hinges may be obtained by means of adjusting the rigidity of the eyes and pins, and also by increasing the yielding of the race ends correspondingly. A proper decrease in the rigidity of the inner bearing race can provide equal loading on the bearing needles, thereby eliminating breakage of the needles and scoring of the race surface.

Holes in parts are sources of stress concentration. Decreasing the harmful effect of holes is achieved with various design solutions.

Fig. 155 shows methods of increasing the fatigue strength in parts with holes. Counterboring the holes from the external sides is desirable (in a case where the shaft experiences large stresses, the other end of the hole at the inner wall of the surface should also be rounded off). Removing flats at the hole significantly decreases stress concentration.

Strengthening the surface of a material at a hole by means of pressing with steel tempered balls (broaching) increases the fatigue of shafts. Ball A (Fig. 155,d) is pressed in to round off the edges of the hole and create favorable residual stresses in the edges of the hole. A special device is used for pressing the inner edge of the hole.

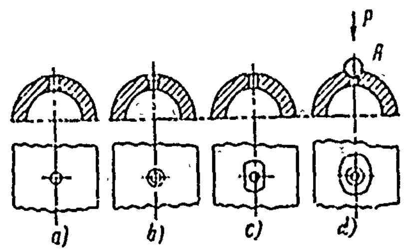

Fig. 155 Methods of Increasing the Fatigue Strength of Parts with Holes:

Key: a) hole in the part is a source of stress concentration, b) hole counterbored from outer side, c) flat removed from outer side of part where there is a hole, d) surface and edge of hole pressed with ball.

To increase the fatigue strength of springs, their preliminary loading behond the yield point is used. A favorable redistribution of internal forces takes place during this. This strengthening process is called forcing.

Regardless of the fact that a material of hollow shafts and axles near the inner surfaces is loaded less intensively than at the outer ones, the inner surfaces must also be subjected to careful machining and strengthening to avoid the appearance of fatigue cracks near them.

The service life of the main assemblies of a helicopter largely depends on the longevity of their parts bearings.

The longevity of general purpose rolling bearings can fluctuate within wide limits because of various factors of a metallurgical and engineering character. In connection with this, the necessary junction bearing reliability in general machine construction is achieved through introducing corresponding coefficients of safety, which is to say by determining an increase in the design load. For parts of aviation equipment, where increased reliability must be achieved through perfecting the construction without increasing the dimensions and weight of the junction bearings, this way is unusable, all the more so because aviation bearings are manufactured of improved materials, have high precisions and are subjected to especially careful control during production.

Bearings used in helicopter construction must be designed as precisely as possible considering the peculiarities of their loading and operations. The proper selection of bearings for main and tail rotor hubs represents considerable difficulties. These bearings work under specific conditions of rocking motion. They fail because of localized wear on the paths of rolling, which has received the name "false brinnelling".

The properties of the lubricant have a great effect on these bearings. The reliable operation of many vital junction bearings in a helicopter is possible only by using special greases and oils. This above all applies to bearings in the axial hinges of the main and tail rotor bushings which absorb considerable axial loads from centrifugal forces of the blades. Analysis of test results shows that during the rocking motion, bearing wear is defined to a significant degree by oxidation processes and insufficient lubrication in the zones of contact between the balls (needles) and the races. The oxidation products of iron obtained during this, mixed with the lubricant, form a unique polishing mixture which causes the rapid wear of the rolling paths.

Oils, and not consistent lubricants, should be used in joint bearings working under a rocking motion in all cases where it is possible with respect to design considerations.

The longevity of rolling bearings essentially depends on the quality of sealing the joint bearings. If the sealing is poor, allowing oxygen from the air to penetrate inside the joints, and also with small volumes of lubricant

and large volumes of air, the longevity of these bearings will decrease noticeably.

The division of a construction during design and manufacture into a large number of separate parts has a very unfavorable effect on its reliability, weight, cost, precision of manufacture and quality of external surface. The striving for a maximum decrease in the number of connections of separate parts has led to "monolithic" construction.

Rigidity ribs, various reinforcements, connecting elements and the jacket skin in a "composite" construction are manufactured separately and then connected, while in a "monolithic" system, they form an organic whole.

Fig. 156 shows a pressed part in comparison with a riveted "composite" construction. The pressed part in many cases possesses high fatigue strength, weight and technological advantages by comparison with parts manufactured by other methods (riveting, machining -- cutting, welding, casting).

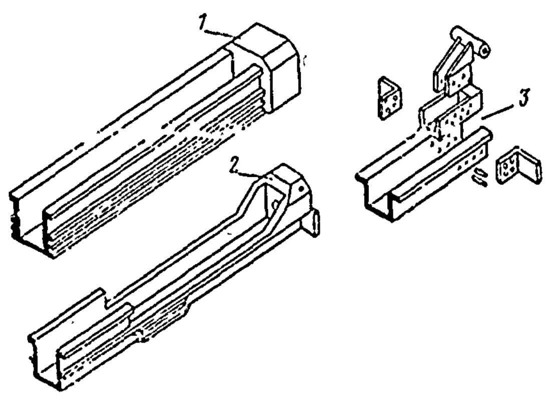

Fig. 156 The Technology of Manufacturing "Monolithic" Constructions:

Key: 1) original stock with pressing excess, 2) part after final machining ("monolithic" construction), 3) same part obtained by riveting ("composite" construction),

In heavy-series production, pressed parts are cheaper than those which are welded, riveted or machined on metal cutting machines. The use of alloyed steels and high-strength alloys of aluminum forces particularly careful attention to be paid to the machining of the surface, since the fatigue strength of the parts depends to a significant degree on the condition of the surface and mechanical properties of the external layers of the material.

Traces of machining, accidental cracks and also corrosion of the surface layers of the material have an extremely serious effect on the strength of the parts.

Fig. 157 presents orientation data on evaluating the fatigue limit of various steels depending on the condition of sample surfaces. The fatigue limit of samples with ground surfaces is set at 100% (line 1); curve 2 represents samples with polished surfaces; 3 -- samples machined with a cutter; 4 -- samples on the surfaces of which were made shallow cuts; 5 -- samples which were not machined after rolling; 6 -- samples whose surfaces were corroded in fresh water; 7 -- samples corroded in sea water. The limits of strength for the material under testing for tension are placed along the abscissa. From the graph it follows that the effect of surface layer condition on the fatigue limit of a material increases as its ultimate strength increases. For example, the steel sample whose surface was not machined after rolling at $\sigma_b = 30$ kg/mm^2 loses approximately 17% σ_a, and the same sample at $\sigma_b = 100$ kg/mm^2 loses approximately 50% σ_a. The fatigue limit of a corroded surface is especially heavily reduced.

Nonferrous metals are less sensitive to surface machining.

Improper tightening of bolts and accidental damage to ground or polished surfaces in vital parts may reduce the fatigue strength of the parts and bring all the efforts of the designer, striving to increase the strength and reliability of his construction, to nought. Fig. 158 depicts a ground bolt made of high quality alloy steel which failed due to the fact that the stamp was placed close to the fillet, which is to say in the zone of high stresses.

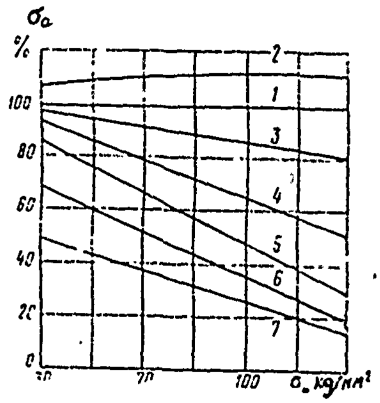

Fig. 157 Dependence of Sample Fatigue Limit on their Ultimate Strength and Surface Condition

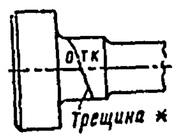

Fig. 158 Bolt which Failed Due to the Appearance of a Fatigue Crack near the Stamp

Key: * crack

In designing, it is necessary to provide measures so as to avoid damaging the surface layers of parts during their assembly and disassembly.

Grinding, polishing, mechanical strengthening of the surface and thermal-chemical treatment of survace layers of a material are used to eliminate surface stress concentrators, i.e., the methods of strengthening technology are taken advantage of.

Methods of Strengthening Technology

The diagram presented in Fig. 159 lists the main methods in modern strengthening technology.

As is evident from a review of this diagram, the strengthening of parts can be achieved by means of conducting special technological operations providing the required surface layer condition of the part.

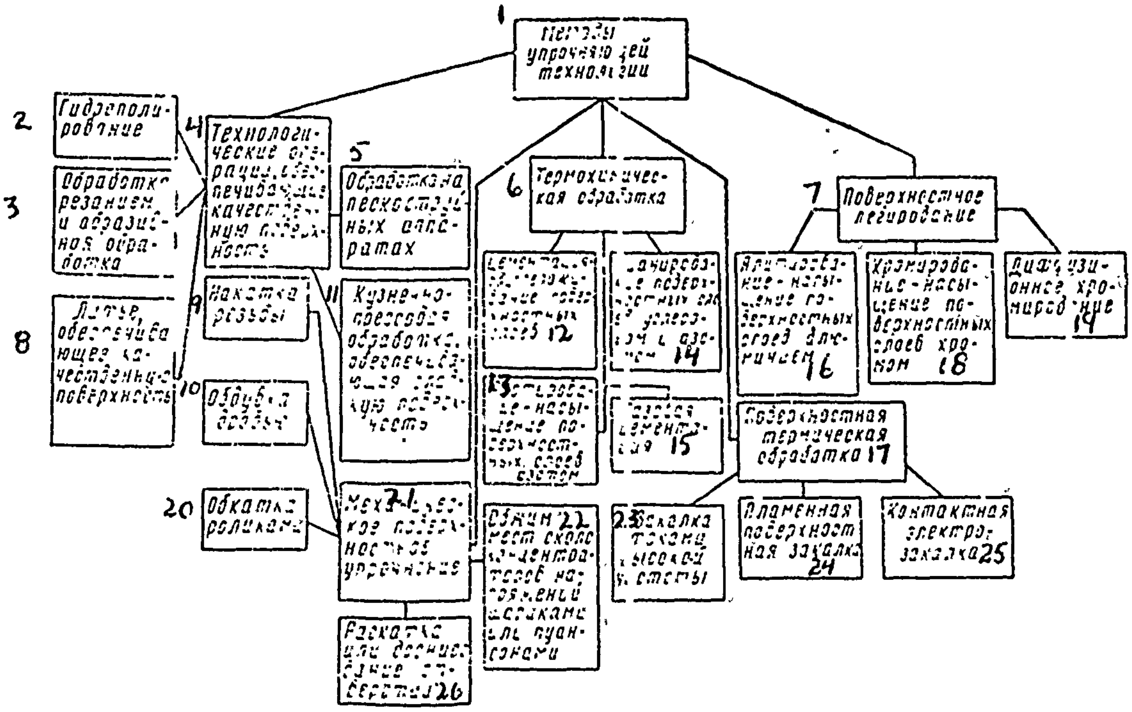

Fig. 159 Methods of Strengthening Technology

Key: 1) methods of strengthening technology; 2) hydra-honing; 3) cutting or abrasion treatment; 4) engineering operations providing high quality surface; 5) sand blasting; 6) engineering treatment; 7) surface alloying, 8) casting, providing high quality surface; 9) rolling threads; 10) shot blasting; 11) forging-pressing, providing smooth surface; 12) cementation -- carbonation of surface layers; 13) nitriting -- saturating surface layers with nitrogen; 14) cyaniding surface layers with carbon and nitrogen; 15) gas cementation; 16) calorizing -- saturating surface layers with aluminum; 17) surface heat treatment; 18) chroming -- saturating surface layers with chrome; 19) diffusion chroming; 20) rolling with rollers; 21) mechanical surface strengthening; 22) pressing places near stress concentrators with balls or punches; 23) high frequency current annealing; 24) flame surface annealing; 25) contact electro-annealing; 26) rolling or broaching holes

The most essential two basic methods of improving the quality of surface layers:

1) strengthening through plastic deformation of the surface layers of the material (rolling with rollers, shot blasting, broaching holes and pressing places near stress concentrators with balls or punches);

2) strengthening surface layers of the material through thermal-chemical treatment (surface annealing with high frequency current, nitriting and so forth).

When strengthening the surface layers of a material through plastic deformation (hammering), roughnesses are smoothed, flash is removed, scratch depth and entry angle sharpness is reduced, and, most important, the external layers of the material of the part are packed. After this treatment, a compression stress arises in the surface layers. They are accumulated with the working stresses, as the result of which the fatigue limit of the part is increased.

Other measures for increasing the fatigue strength of a part whose surface can have friction corrosion is cold working this surface.

Cold-rolled tubing made of highly alloyed steels types 30Kh GSA and 40 Kh NMA is used for blades having steel tubular spars. The fatigue strength of steel spars can be increased by 50 to 100% through the use of mechanical strengthening.

Through the use of cold working, the fatigue limit for a steel spar may be increased to a value σ_a min = = 20 - 30 kg/mm^2 at σ_t = 20 - 25 kg/mm^2, and for a duralumin spar of AV-T1 alloy, the value can reach σ_a min = = 5.5 - 6.0 kg/mm^2 at σ_t = 6.0 kg/mm^2.

The fatigue limit of a steel spar without the use of cold working may have a value of σ_a min = 12 - 13 kg/mm^2 at σ_t = 20 - 25 kg/mm^2; and for a duralumin spar, σ_a min = 3.8 - 4.2 kg/mm^2 at σ_t = 6.0 kg/mm^2.

Cold working is the most active means for increasing the reliability and strength reserve in blades.

The strength of cold worked duralumin spars can be sharply decreased if while bonding the framing to the spar is heated to a temperature close to 200° C and greater.

Therefore, the temperature while bonding must be carefully controlled.

Excessive cold hammering of a surface can lead to micro cracks which create the concentration of stress beneath the hammered layer, which in turn can be a reason for failure of the part.

When strengthening the surface layers of a material through thermal-chemical treatment, besides changing the chemical composition and physical properties of the material, its volume is also increased due to the components introduced during treatment, as the result of which compression stress arises in the surface layers. Therefore, along with an increase in hardness and wear resistance, an increase in fatigue strength also takes place.

The combination of various methods of strengthening is highly effective. For instance, the fatigue limit of steel parts can be increased by rolling with rollers after surface annealing with high frequency current.

The serious effect of aggresive and adsorptionally active media on the fatigue strength of parts forces us to turn to a covering for the purpose of eliminating the immediate contact of the active medium with the surface of the parts.

It is necessary to eliminate the possibility of corrosion damage to pressed spars in the process of their production the same as under operational conditions. External and inner crystallic corrosion can sharply reduce the fatigue limit. Therefore, a metal with high anticorrosion resistance must be chosen for blade spars and special measures should be taken in production to protect the spars from corrosion through the use of galvanized coverings after intermediate operations in its treatment (for instance, anodizing).

However, the covering itself also has some effect on the fatigue strength of the part. This effect is sometimes insignificant (with lacquer covering, covering with zinc, oxidation), and in some cases, the covering (when chroming, nickel plating or copper plating) noticeably decreases the fatigue resistance of the parts. At the same time, the decrease in fatigue strength to a significant degree offsets the positive effect of protecting the surface layers of the part from the aggresive medium.

Effect of the Dimensions of Parts on Their Fatigue Limit

The dimensions of samples have a very essential influence on the value of the fatigue limit.

When the samples's dimensions are increased, the fatigue limit decreases. This is especially noticeable when testing samples having stress concentrators. A decrease in the fatigue limit with an increase in the dimensions of the parts has a great practical meaning. It must be considered when designing large parts since mistakes might otherwise be made in the area of re-evaluating the material.

The phenomenon of decreased fatigue strength with an increase in parts dimensions is not yet fully explained. Two hypotheses have been brought forth concerning this question. According to the first of them, with an increase in such dimensions, the probability of the appearance of various defects (hollows, microcracks, impurities, cutting traces and so forth) in the surface layer increases with an increase in the part's dimensions. The development of fatigue cracks usually begins in these places. The second hypothesis explains the decrease in fatigue limit with the increased part's dimensions by the fact that during machining (cutting) small dimensioned samples, plastic deformations of the surface layer take place to a relatively larger depth than in samples of large dimensions. Residual stresses arising during this have a favorable effect on the fatigue strength of the part.

The hypotheses presented do not exclude each other but rather are additive.

The relationship between the fatigue limit of a given part and the fatigue limit of a sample (standard) 6 - 12 mm in diameter is called the scale factor and is designated ε_{sc}. In this, it is supposed that the geometric form of the part's section, the condition of its surface layers and the samples are identical.

Fig. 160 depicts a graph of the scale factor's dependency on the diameter of the sample under bending and torsion. The graph is constructed on the basis of tests under a symmetric cycle of changing stresses.

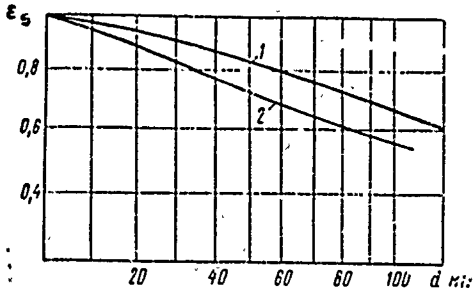

Fig. 160 Graph of Scale Factor Dependency on Diameter under Bending and Torsion of Round Bars

Key: 1) carbon steel, 2) alloyed steel

At the present time, tests for fatigue strength are conducted on parts and components of a helicopter which are made to actual size. However, the material from these tests on hand is still insufficiently widespread systemized, making its use in computations more difficult.

Overall Evaluation of the Effect of Material Surface Layer Condition of a Part on the Value for Fatigue Limit

The effect of parts' surface layer conditions on their fatigue limit was briefly illuminated above. In calculations for fatigue strength, it is necessary to evaluate this effect with coefficients going into the design formulae.

The relationship between the fatigue limit of a sample whose surface is in the same condition as that of a projected part to the fatigue limit of a sample with a ground surface is called the surface factor of the part ε_s.

The surface factor ε_s depends on all the reasons listed in the preceding paragraphs and is a product of the coefficients, considering the values of each of the causes affecting the fatigue limit:

$$\varepsilon_s = \varepsilon_1 \varepsilon_2 \varepsilon_3 \cdot \cdot \cdot \varepsilon_n .$$

These coefficients, in turn, are relationships between the fatigue limit of a sample whose surface was machined in a corresponding manner to the fatigue limit of a sample with a ground surface.

The coefficients listed can be divided into two groups: coefficients less than one, which reflect the effects of factors which decrease the fatigue strength (marks, nicks on the surface, corrosion of surface layers and so forth), and coefficients larger than one which reflect strengthening through special treatment of the part's surface layers (treatment with rollers, shot blasting, thermal-chemical treatment and so forth).

In a number of cases these values may be derived from textbook literature. They must sometimes be evaluated approximately with consideration for materials in the literature and personal experience.

Section 3

Parts Connections

Transmittal of Loads

When designing parts connections in a helicopter construction, particular attention should be paid to transmittal of loads from one part to another and the designer should strive so that a stress "jump" does not arise at the point of transmittal. The force flow in connections must not undergo any sort of change in its direction. Under the action of tension stresses, as well as in the tension zones of connections working under bending, it is always necessary to consider the value of the fatigue limit of the parts and their connection when designing.

Local stress concentrations do not arise in a properly designed monolithic construction. However, high operational reliability of such a construction can be insured only in a case where its connection with the parts joined will not lead to the appearance of high local stresses causing fatigue failure.

Fig. 161 shows various types of connections between two perpendicular planes. We will look on the right plane as being "loaded" at point A on the left end of the contact line and point E on the right end:

a) the width of the loaded plane is constant along the contact line. A sharp change in stress takes place at points A and E;

b) the loaded plane is severely tapered. At point A, the width of the loaded plane is equal to zero. Further, the width increases linearly, reaching its full value at the end of the contact line. The concentration of stress in the loaded plane sharply decreases. However, the effect of stress concentration on the loaded plane is observed at point E;

c) both planes are severely tapered. The concentration of stress in both planes is decreased in this case;

d) planes with an optimal change in width. Both planes are identical. The width of the loaded plane must increase smoothly from point A to point E. At some distance from point E, the width of the plane can again decrease until such time as the distribution of stress becomes equal. The dimensions of the plane should not be established with a reserve beyond the contact line.

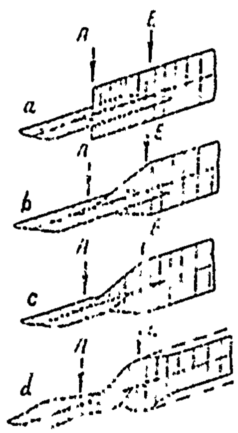

Fig. 161 Transmission of Load in Joint between Two Perpendicular Planes

Fig. 162 shows the distribution of force on a skin. Normal stresses in loaded band 1 must decrease from point A to point E as the result of shear deformation and be transmitted to loaded skin 2.

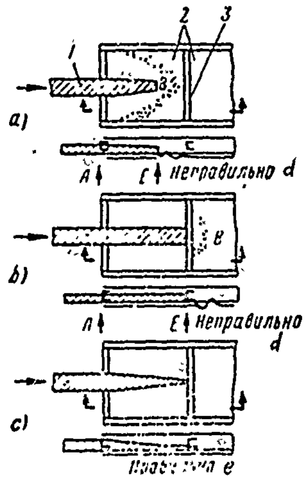

Fig. 162 Proper and Improper Transmittal of Loads at Point of Load-Bearing Part End:

Key: a) loaded band terminated on skin section, b) constant section loaded band terminated on reinforcing rib, c) changing section loaded band terminated on reinforcing rib, d) improper, e) proper, B) wrinkling of skin

The loaded band should always be carried to reinforcing rib 3 so that the end of the band is connected with two sections of the skin having high rigidity against shear (b) and (c).

Termination of the band in the middle of the skin section (a) is extremely detrimental for the skin and will lead to its premature failure.

Since the band must fully transmit its load to the skin sections connected with it, the cross section on its end must decrease to practically zero (c).

If the loaded band in a solid plate has a constant section to its end (b), concentration of normal stresses will take place in this case, significantly overloading the skin near the band.

Fig. 163 presents examples of joint constructions for transmitting loads.

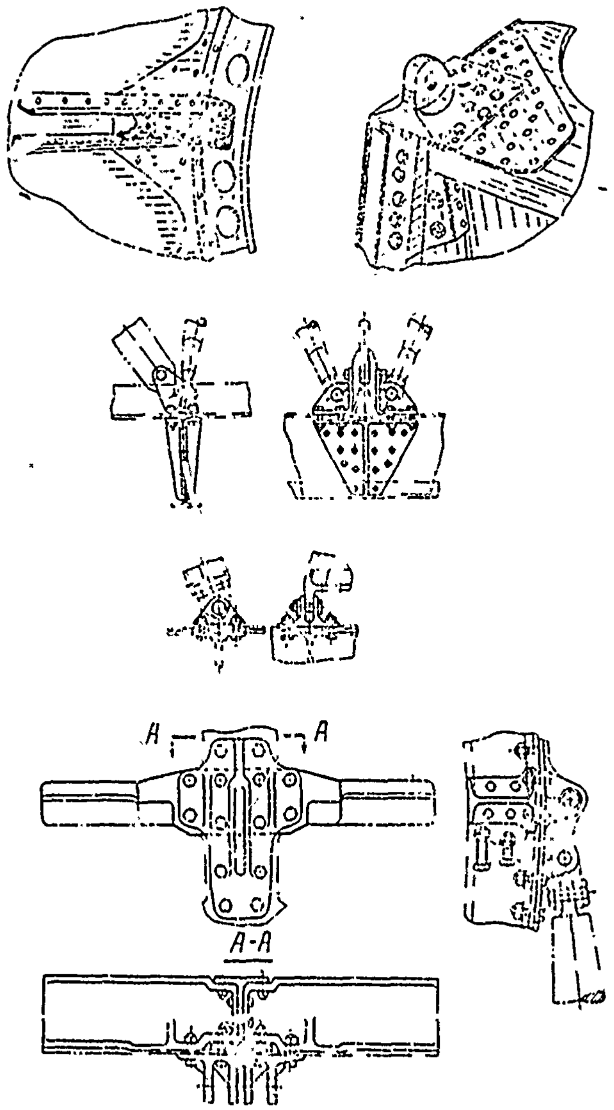

Fig. 163 Constructions of Joints for Transmitting Loads

Types of Parts Connections

There are two types of connections: permanent and disconnecting. Permanent connections include:

a) riveted;

b) bolted;

c) bonded;

d) welded;

e) soldered;

f) special.

When selecting the type of connection for parts, one should be guided by considerations of their strength and technology of manufacture.

As was already noted previously, stress concentrators in the form of holes have a great effect on the fatigue strength of a part. Therefore, for these parts, it is desirable to use bonded and soldered connections.

Disconnecting connections are divided into:

a) stationary;

b) slightly movable;

c) movable.

Determination of the "movability" of a connection is highly essential for the designer.

The movability of a connection is determined not by the amount of mutual movement of the assembled parts, but by the presence of assembled parts which move relative to each other under the action of corresponding loads (Fig. 164).

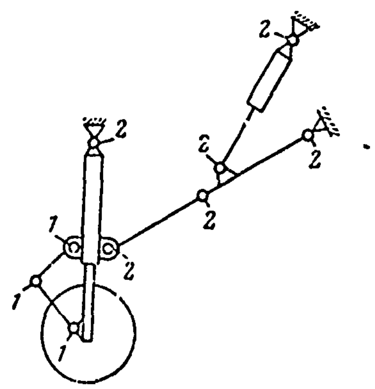

Fig. 164 Examples of Movable (1) and Slightly Movable (2) Connections

A movable connection is characterized by the movement of assembled parts relative to each other under the action of the design load.

Slightly movable connections are characterized by the absence of relative movement of the assembled parts under the action of design loads. These connections include, for instance, gear strut connections.

Slightly movable connections should be checked like movable connections under the same loads which they experience during their relative movement. For instance, gear strut joints should be checked for loads which arise in the process of retracting the gear. In this case, the connections are considered movable.

According to existing recommendations, allowable bearing stresses are used depending on the degree of movability of the connection.

For stationary connections

$$\sigma_{bs} = (1.0 - 1.5)\,\sigma_b.$$

In this, the lower limit indicates stationary breakdown connections, for which

$$\sigma_{bs} = \sigma_b,$$

and the upper limit indicates stationary permanent connections, for which

$$\sigma_{bs} = 1.5\,\sigma_b.$$

For slightly movable connections

$$\sigma_{bs} = (0.5 - 0.65)\,\sigma_b.$$

For movable connections

$$\sigma_{bs} = (0.2 - 0.4)\,\sigma_b.$$

With a uniform material for a movable connection without lubrication, in approximating one can use

$$\sigma_{bs} = 0.2\,\sigma_b,$$

and with lubrication provided,

$$\sigma_{bs} = 0.3\,\sigma_b.$$

For a construction with a low coefficient of friction under conditions of using corresponding materials, it can be considered that

$$\sigma_{bs} = 0.4\,\sigma_b.$$

Allowable bearing stresses for movable and slightly movable connections depend on the character of the fit of these parts, which are made with a moving fit, the frequency of load repetition, stress acceleration and so forth. All this will lead to an uneven distribution of bearing stresses in the hinge by comparison with a nonmovable connection.

It is necessary to keep in mind that hinged connections with rocking bearings (for instance, in the control rods) cannot be considered movable connections. The connection of the axial hinge bolt and the ball bearing inner race is stationary, and the movability of the connection is created by the ball bearing itself.

It is not necessary to calculate holes in a steel part in which the outer race of a bearing is pressed against

collapse, since it is known to be strong under stress. If the hinge part is made of a light alloy or nonmetallic material, then it is necessary to provide installation of an intermediate steel bushing in which to install the bearing outer race.

Riveted Connections

The rivet material and its diameter is selected on the basis of calculating a connection for strength, and the type of rivet and the shape of its head is selected depending on aerodynamic, design and engineering requirements.

The length of the rivet is determined depending on its diameter and thickness of a riveted combination according to branch norms. For computation of the length of a normal rivet (Fig. 165), it is possible to use the formula

$$L = S + 1.5d,$$

where S -- thickness of the riveted set in mm;

d -- rivet diameter in mm.

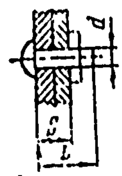

Fig. 165 For the Selection of Rivet Length:

Key: d) rivet diameter, S) thickness of riveted set, L) rivet length

When selecting the diameter of a rivet, it is necessary to keep in mind that the thickness of the riveted set must not exceed 5 - 6 diameters of the rivet pin. Exceeding this relationship will lead to concealed ruining of the riveted connection in the form of poor filling of the hole due to distrotion of the rivet pin in the set hole. If the rivet diameter is more than 8 mm, it is recommended that bolted connections be used.

Riveted connections working toward breaking away the rivet head are not recommended for use. In these cases, it

is desirable to change to bolted connections.

When possible, the connections should be made in double shear.

Fig. 166 presents a working diagram of a single shear riveted connection. When the joint is loaded by force P, a bending moment arises. Under the action of the bending moment, the skin warps at the point of the joint, and the rivet will work not only on shear but also on breaking. To decrease skin deformation and improve the working conditions of the rivets, it is expedient to use a thick joint insert and insert the rivet not in one, but in two rows along each side of the joint.

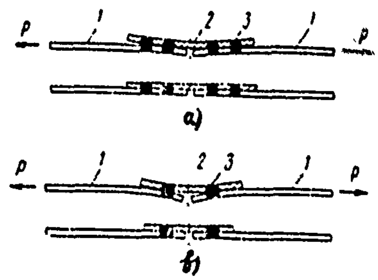

Fig. 166 Single Shear Riveted Connections with Insert:

Key: a) rivets installed in two rows, b) rivets installed in one row, P) force acting on the connection, 1) skin, 2) insert, 3) rivet

Like bolts, the number of rivets in one row in the direction of the force's action is limited due to the unevenness of force distribution along the rivets (Fig. 167). When acting force P is relatively small, which is to say comprises a small part of the force destroying the connection, the parts of this connection are loaded especially unevenly. First an extremely uneven compression of the clearances occurs, and then the rivets are sequentially engaged into work approximately according to a parabolic law, with which the rivets lying closest to the place where the force is applied are loaded more under strong equal conditions.

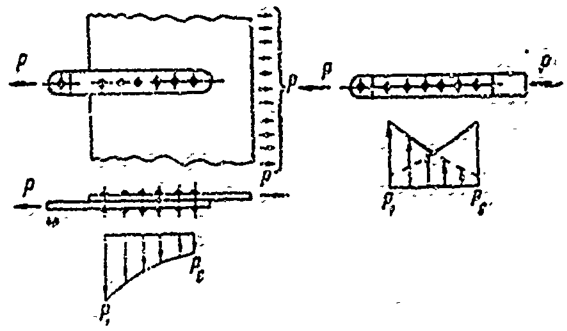

Fig. 167 Distribution of Load Along Rivet of Parts Joint

When riveting plastic materials, this unevenness appears to a lesser degree than with brittle ones, and it is therefore not recommended to insert more than 6 - 8 rivets in one row. In a case where the rivets necessary to transmit the force cannot be placed in one row, they are placed in two or more rows in staggered order.

Considering requirements of aerodynamics, it is desirable to accomplish the connection of sheets having a large curvature with flush head rivets having a head cone angle $\alpha = 90^{o}$.

In places where it is impossible to introduce a support, pop rivets, chord rivets, hollow rivets and so forth are used.

There are norms for the rivets used in the aviation industry.

An example of rivet designation: 3560A-2.6-5, where 3560A -- number showing that the rivet is manufactured of D18p material and has a semicircular head shape, 2.6 -- rivet diameter (d mm), 5 -- rivet length (L mm).

Bolted Connections

Bolted connections are computed similarly to riveted connections. It is expedient to take destruction loads on bolts from tables. It is not recommended that bolts having a diameter under 6 mm be used in load-bearing connections due to the possibility of the bolt head breaking off when the nut is tightened.

Bolt length (Fig. 168) is computed according to the formula

$$L = S_s + S_w + H_n + \Delta h,$$

where L -- bolt length, mm;

S_s -- sheath thickness, mm;

S_w -- washer thickness, mm;

H_n -- nut height, mm;

Δ_h -- reserve of bolt threaded portion, equal to 1.2 - 2 times the thread pitch in mm.

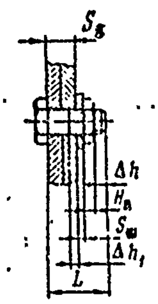

Fig. 168 On Selecting Bolt Length

In vital connections working under shear, it is necessary to make provisions so that the bolt threads do not work under collapse, which is to say so that $\Delta h_1 = 0$. The bolt type is selected depending on requirement stipulated for the connection.

A certain clearance can be present in a butt joint, depending on the precision of bolt manufacture and the selected fit of it in the hole.

When applying changing forces and moments to a butt joint, the bolt moves in the hole. As the result of this, the surface layer of the bolt material and that of the hole are destroyed from the stress concentrations arising.

The fatigue strength of a bolted connection (for instance, butt joint of the blade with the axial hinge body) can be increased with the following measures;

1) it is necessary to set the fit and precision for the manufacture of the bolt and the butt joint hole in such a manner that there is no clearance between the bolt and the hole not only after assembly of the joint but also during the process while this joint is in operation. In this, it is necessary to consider the operational requirements for a butted joint, for instance, the convenience of assembly and disassembly of the joint under field conditions and so forth;

2) it is necessary to use anti-seizing paste when inserting the bolt in the hole;

3) in especially vital butt joints, it is expedient to use tapered bolts. When assembling a butt with tapered bolts, the possibility exists not only of eliminating clearance between the bolt and the hole but also of creating a preliminary axial tension in the joint. Tightness of the tapered bolt must be such that under the action of the forces and moments arising in the butt joint, this clearance does not appear due to flexible deformation of the butting elements.

The use of a tapered bolt connection significantly increases the reliability of the butted joint.

The deficiency of a tapered bolt connection is the large labor consumption of its manufacture by comparison with the manufacture of a cylindrical bolted connection.

In designing joints whose butts are accomplished with cylindrical bolts (for instance, flanged butts of transmission shafts, connection between the main reduction gear housing and the frame and others), preliminary bolt tension is also used and isdetermined from requirements outlined for the joint:

1) transmission of load from one part to another with a force of friction arising on the face surface of the butt;

2) creation of a definite minimum pressure on the butt of the parts connected to provide its closeness and tightness;

3) the absence of hammering on the butt during the presence of changing axial loads on the joint.

Stresses from tension in bolted connections are checked by one of the methods listed below:

-- measuring the torque moment with calibrated wrenches limiting the amount of tightening moment;

-- measuring the angle of nut rotation after it touches the support surface;

-- measuring the lengthening of the bolt.

The first and second methods are used for various butting bolted connections. Both methods are inherently inaccurate in measuring tension. In the first method, the inaccuracy is obtained due to the fact that the force necessary for tightening fluctuates depending on the condition of the threads and the support surfaces. The inaccuracy in the second method is obtained due to some indetermination of the nut position at the initial moment it touches the support surface. A combination method of tightening is sometimes used, in which the nut is first tightened with a calibrated wrench, and it is then turned by a definite angle. The most accurate is the last method, which is measuring lengthening of the bolt. This method is widely used for monitoring vital bolted connections.

Washers are used in connections for the following purposes:

a) covering the zone of the nonworking part of the thread (run-out, turns for providing the required bolted connection tightness);

b) protecting the anticorrosion covering layer from damage when threading on the nut;

c) increasing the area of compression beneath the nut and bolt head;

d) equalizing the surface (special radiused washers are used;

e) locking the nut (safety washers are used).

It is necessary that the installation of transfer threaded bushings (Fig. 169) be provided in a number of threaded connections for inserting screws into parts made of light alloys. The installation of threaded bushings prevents the threads from being worn and torn out during repeated assembly and disassembly of the joint. The threaded bushings screw into a tight thread and are locked by punching, and in vital connections, they are locked with threaded or cylindrical pressed-in pins.

Fig. 169 Installation of Threaded Bushings in Parts Made of Light Alloys

Bonded Connections

The absence of stress concentrators, high surface quality, better sealing and other factors are reasons for wide usage of bonded connections in helicopter construction.

The use of bonded connections can be recommended (if they correspond to requirements for strength and reliability in operation) in constructions of the tail portion of the helicopter blades, bulkheads and panels of the fuselage and similar parts.

In designing bonded connections, it is necessary to be guided by the following considerations:

a) bonded joints must not have parts for which heating up to the temperature of glue polymerization is unusable;

b) it is necessary that the parts of the bonded framing allow pressure to be created and heat to be applied in the zone of bonding;

c) clearances more than 0.1 mm must not be allowed between the surfaces of bonded connections which are pressed against each other before the application of the bonding material. This requirement is caused by the decrease in strength of a bonded connection if the bonding material layer thickness is increased;

d) bonded connections work satisfactorily under shear and very poorly under asymmetric breakaway.

To increase the resistance of bonded seams to forces directed toward peeling off the bonded surface, the seam ends must be fastened with rivets, precision or roller welding

or by some similar method. In the case of thick skins and the necessity for riveting the ends of the bonded se ns with flus rivets, it is expedient to bon a metal band of the necessary thickness in these points n the construction beforehand.

The type of glue must be selected in conjunction with the design of the actual joint, requirements of strength, operating conditions and engineering possibilities in production. It is desirable to use glue in the form of a free or reinforced film (fabric impregnated with glue). This provides a glue layer which is even in thickness, guaranteeing the minimum weight of the bonded construction.

Bonded connections are used in three-layer constructions (panels). The term three-layer panels are understood to mean a composite construction consisting of thin skins (load-bearing layers) with fillers placed between them. These constructions are distinguished by their minimal weight, rational form, high surface quality, high strength in operation due to the absence of stress concentration, and good insulating properties (as regard to heat and vibration). The construction of a three-layer panel compares best of all in a mechanical sense with that of an H-beam. The role of the beam bands is played by the two load-bearing layers of the panel and the role of the wall is played by the filler.

Fig. 170,a shows three-layer flat panels with various fillers.

Honeycomb filler made o luminum foilis used in three-layer panels made of igt alloys in the majority of cases.

Fig. 170, b shows the basic form of honeycomb and its variations. The following directions are also shown on the drawing: along the direction of the foil band -- longitudinal; its perpendicular -- lateral. Drain holes 0.1 mm in diameter must be provided on the bonded surfaces of each cell of honeycomb filler for exhausting air and volatile components of the glue during the process of the glue's polvmerization.

The presence of drain holes in the walls of honeycomb also allow the vacuum method to be used for bonding skins to honeycomb filler.

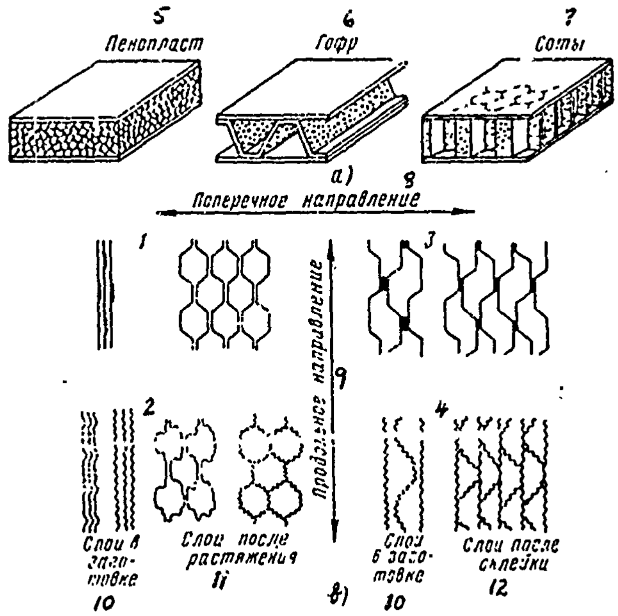

Fig. 170 Three-Layer Panels:

Key: a) types of fillers, b) three-layer panel honeycomb, 1) rigid, 2), 3) and 4) flexible, 5) plastic foam, 6) corrugated, 7) honeycomb, 8) lateral direction, 9) longitudinal direction, 10) layer in stock, 11) layer after stretching, 12) layer after bonding

Honeycomb fillers which have the form of a wedge should not be used with sharp edges on the top, since it is difficult to obtain a good edge quality when milling this type of honeycomb. The filler should be constructed in the form of a sectioned wedge.

The filler material can be roughed out when it is still in the form of a closed bundle. With high requirements for contact precision between the cell walls and load-bearing layers, this treatment is not sufficient. The open body, consisting of cells (Fig. 171), is machined in the following manner: the cells are filled with liquid or paste and the filler hardens and supports the honeycomb walls; the honeycomb surface is machined on a copying milling machine, after which the hardened medium is again liquified and then removed.

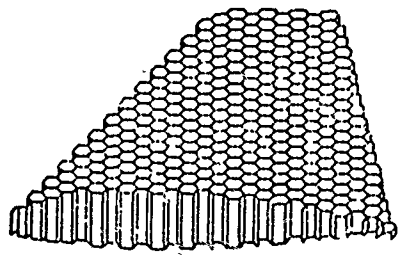

Fig. 171 Honeycomb Obtained by Milling on a Copier

The following are used as temporary filler materials:

-- water (frozen);

-- plaster of Paris (set);

-- synthetic material (hardened).

The basic form of honeycomb is hexagonal.

The load-bearing layers are connected with the walls of the honeycomb by means of bonding or soldering.

Shear loads in the plane of the honeycomb wall are transmitted to the load-bearing layer of the panel through both seams connecting the honeycomb wall with the load-bearing layer. In this manner, regardless of the very thin foil, there is a sufficient number of connecting surfaces working against shear between the load-bearing layers.

The quality of bonding depends on the type of glue, the frequency of glued surfaces and the method by which hardening of the glue is achieved. There are two methods of bonding: by means of vacuum and excess pressure.

The three-layer panel is placed in a rubber sack. When air is pumped out of the rubber sack, a vacuum is created inside it. Air from the honeycomb filler bleeds out through the drain holes in the honeycomb walls.

A pressure differential is created inside the rubber sack and on its outer surface. This pressure differential

creates the necessary force on the inner surface of the panel skin. Electric heating elements which create the required temperature for polymerization of the glue film are mounted in the rubber sack.

In the second method of bonding, the three-layer panel is installed in a device which has rubber sacks installed on its upper and lower surfaces. The upper cover is fastened to the lower part of the device. Air is forced into the rubber sacks. A required force is created on the outer skin of the panel. Heating elements create the necessary temperature for polymerization of the glue film.

Hot air is bled out of the honeycomb filler through the drain holes.

Fig. 172 shows some of the simplest designs for edges of three-layer panels. The use of one type of edge construction or another depends on the purpose of the panel. Fastening connecting parts to panels is a complex operation. Normal fastening means such as bolts and rivets must pass through the entire thickness of the three-layer panel. When tightened, they can destroy this panel.

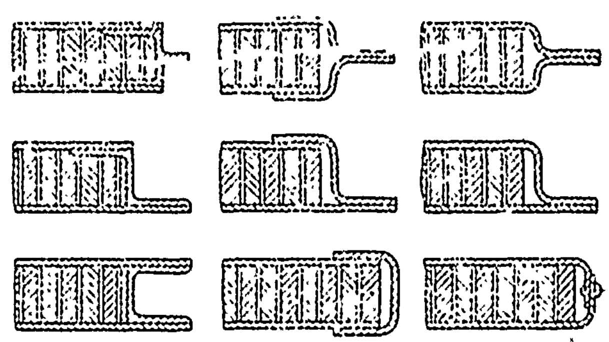

Fig. 172 Framing Three-Layer Panel Edges

Fig. 173 shows examples of connecting parts with a three-layer panel.

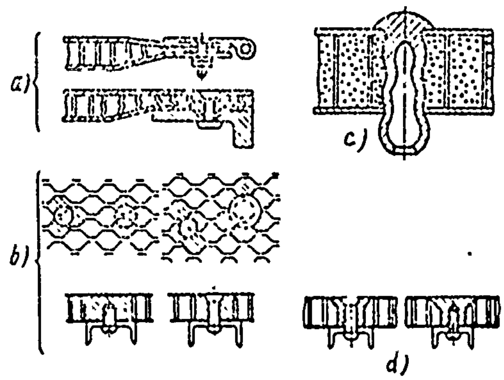

Fig. 173 Connections between Parts and a Three-Layer Panel

Key: a) compression of honeycomb filler, b) filling honeycomb cells with resin, c) pop rivet connection, d) connection with synthetic material bushings

Compression of the honeycomb filler is used only for non-loaded parts for the purpose of forming recesses in the panel for attaching parts.

Pouring resin into the filler cells (see Fig. 173, b) forms a core through which screws or flush head rivets can be driven.

When pop rivets are used (see Fig. 173,c) a better connection of both ends of the rivet with the skin occurs and a spacing bushing is formed. Bushings of synthetic material (see Fig. 173,d) are used for flush head rivets, screws or bolts.

Fig. 174 shows various means of covering skin butt joints.

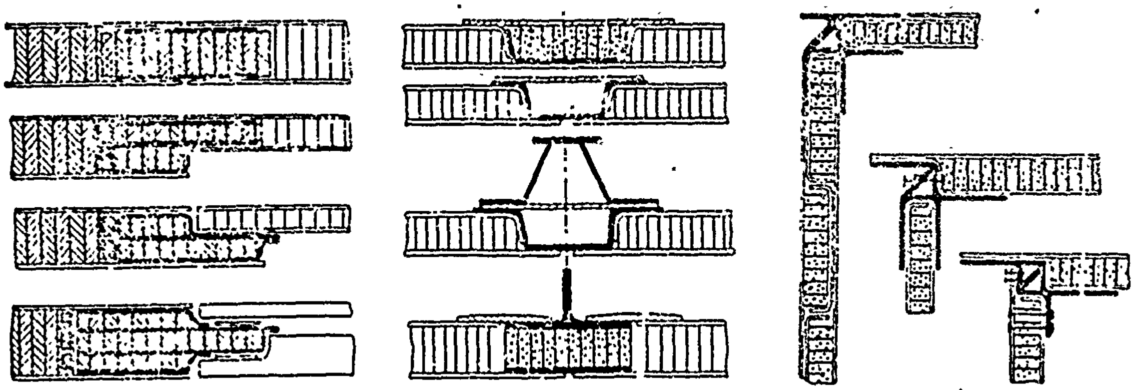

Fig. 174 Types of Skin Butt Joint Coverings:

Key: a) overlapping butts, b) three-layer panel inserts, c) design formed three-layer panel angle joints

When butting three-layer panels with other types of construction (for instance, with stamped parts) inserts depicted in Fig. 174, b are used.

Design formation of angle joints is shown in Fig. 174,c. The transmittal of forces which, acting on one side of the panel, load only one load-bearing layer, represent great interest in constructions made of three-layer panel. These forces are transmitted to the second load-bearing layer only through the filler without special connecting elements, the installation of which would require cuts in the load-bearing layers of the panel.

Fig. 175 shows undesirable (a) and desirable (b) connections.

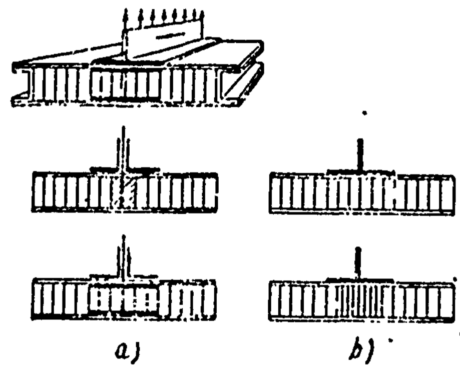

Fig. 175 Design of Joints for Transmitting a Lateral Force to a Three-Layer Panel

In the case of local loads acting along a tangent to the skin, the strength and rigidity against shear of the panel and its connection with the load-bearing layers has importance, and with loads acting perpendicular to the skin surface (separation), the strength of the honeycomb filler against stretching and the strength of the connecting seam between the honeycomb and the load-bearing layers are important.

Methods of Transmitting Torque Moments

The methods for connecting parts and junctions which transmit torque moments are distinguished by their wide variety. Selection of a connecting method is largely determined by the amount of torque moment transmitted, conditions of assembly and disassembly of the joint, the usability of connecting parts whose manufacturing technology is already mastered in production and similar factors. In a number of cases, the connections must provide transmittal of bending moments and axial forces in addition to the torque moment.

A rational method of transmitting the torque moment can be chosen with consideration of all factors which determine the working conditions of the connection, simultaneously considering the engineering capability and economy of its production.

Transmittal of Torque Moments Using Evolute Splines

This method is widely used in helicopter construction, especially in loaded and vital connections.

The wide use of evolute splines is explained by their several advantages by comparison with splines having a triangular, trapezoidal or rectangular profile. They possess high equality in strength.

The radius in the groove can be very small, decreasing the concentration of stresses at the tooth base.

When designing splines for part sections (Fig. 176,a), it is necessary to be guided by standards and listed norms.

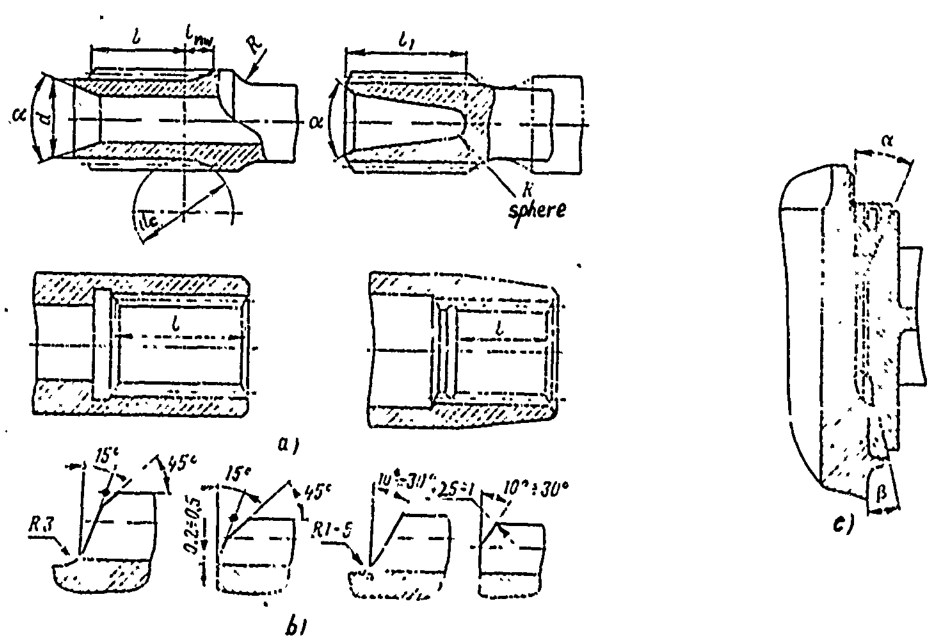

Fig. 176 Designing Splined Connections

Key: a) splined section of part: l) working length of spline; l_1) length of shaft turning, l_{nw}) nonworking part of splines; d_c) cutter diameter, b) recommended shape of spline edges, c) centering parts connected with spline along two beveled surfaces

The working length of the spline 1 is determined from calculations against crushing, using recommended values. In this, it is necessary to consider that an increase in spline length will not always lead to desirable results, since local values of stress can be significantly larger than average design values as the result of production errors.

The exit radius of the splines, which is determined by cutter diameter d_c is chosen out of engineering condiderations. If the designer is not limited by arrangement requirements in the selection of spline exit radius, he can be guided by the following relationship between shaft diameter D_s and cutter diameter d_c:

$$d_c \geqslant (0.6 - 0.7)D_s + (10 - 20) \text{ mm.}$$

When calculating spline connections, equal loading along the length of the spline is assumed. To provide this conditions, it is desirable to have a changing section of the shaft and bushing along the length of its spline portion. This is usually achieved by a conic turned opening inside the shaft and by the manufacture of the external bushing surface according to that cone. The dimension of the radius in the transfer from the spline profile to the groove circumference is selected depending on production conditions. The groove, manufactured with one radius of transfer from the profiles of two neighboring splines, provides high strength as the result of decreasing stress concentration.

To decrease specific pressures on the spline edges during misalignment as a result of production errors and to strengthen splines on the ends of spline sections, chamfers are formed as shown in Fig. 176, b.

To prevent hammering in loaded connections, the splines are covered with a 3 - 5 micron thick layer of lead or copper by an electrolytic method. The presence of an oil film on the surface of contact of the splines as well as the different hardness of their surfaces promotes the prevention of hammering.

In connections having evolute splines, the majority of them are centered along their lateral surfaces. Centering of the main rotor hub center on the reduction gear shaft is accomplished with centering cones (see Fig. 176,c). The lower angles α and β, the lower the value of tightening force required to provide the necessary tension. However,

for convenience in disassembling the joint, it is desirable that angles α and β be made somewhat larger than the angles of self-braking, whose values are determined by the coefficient of friction on the contact surfaces. The usual angles for parts manufactured out of steels are $\beta = 15^{\circ}$, and $\alpha = 30^{\circ}$. To extract the upper cone, special places (turnings, threaded holes) are provided for insertion of a puller.

In the majority of cases, the cones are made in two halves, which guarantees the required interference, both along the conic and along the cylindrical surfaces.

In the transmittal of a torque moment using evolute splines working under conditions of shaft misalignment (Fig. 177,a), it is necessary that the following conditions be met:

a) provide the possibility for free misalignment of the centerlines through a clearance in the teeth of the spline sleeve while observing conditions of strength and working capability;

b) introduce corresponding centering of the outer and inner engagement sleeves. This is especially important at high revolutions, when displacement of the shaft might lead to the appearance of imbalance and additional forces on the support bearings;

c) provide lubrication of the half-sleeve engagement;

d) provide ease in assembling the connecting units.

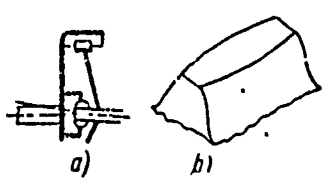

Fig. 177 Transmittal of a Torque Moment with Evolute Splines Working under Conditions of Transmission Shaft Centerline Misalignment:

Key: a) diagram of spline sleeve, b) tooth edge correction to obtain barrel shape

To provide the extended working capacity of such a sleeve, the manufacture of splined engagements with a high degree of accuracy (no less than second class) is required. In some cases, it is expedient to burnish and file the teeth under conditions of misalignment on a special installation.

In design, it is necessary to consider that the work of splines under conditions of shaft misalignment differs sharply from their work when the shaft centerlines coincide in connection with the fact that they teeth are not in contact along their entire length. Shaft misalignment will lead to a sharp change in stress along the tooth.

When a spline sleeve is working under conditions of shaft misalignment, deformation of the tooth takes place due to bending, twisting and contact collapse. The failure of teeth working under conditions of shaft misalignment may occur as a result of fatigue of the splined tooth material due to the combined action of bending and torsion stresses and contact stress.

When designing such splined sleeves, it is expedient for strength to increase the number of their teeth and decrease spline length. To reduce the maximum stresses of collapse, tooth flanking -- correction of the tooth edges along their length (see Fig. 177,b) -- is used in a number of cases. In this, a small layer of material is removed from the crown of the outer engagement at the tooth edges and the teeth take on a barrel-formed shape in plan.

Transmittal of Torque Moment Using Gace Splines

In the practice of helicopter construction, this type of transmittal is used in connections of the tail rotor hub with the reduction gear shaft, in shaft part connections and so forth.

Under action of the torque moment, the splines attempt to move out of engagement. To avoid this, bolts which must provide the necessary preliminary tightness of the joint with axial force P (Fig. 178,a) must be installed in the joint construction.

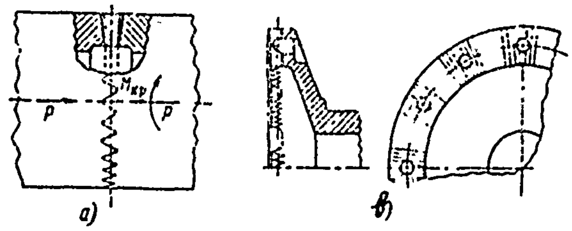

Fig. 178 Transmittal of a Torque Moment with Face Splines:

Key: a) load on abutment of parts with face splines, b) segmented face band

If according to calculations, collapse stress σ_{co} is insufficiently high, the splines may be formed with segments along the entire contacting surface as shown in Fig. 178,b. This allows the weight of the part to be decreased and simplifies its machining.

Transmittal of a Torque Moment through the Force of Friction

In flanged connections which are held with bolts, it is possible to provide transmittal of a torque moment through the force of friction which arises on the face surfaces of the joint. With a given flange dimension, the value for the coefficient of friction and the torque moment transmitted define the necessary tension forces and determine the dimensions of the tension bolt. It is necessary to keep in mind that in calculation, presence of an equal specific pressure along the entire contact surface is assumed. However, flanges in constructions are not absolutely rigid and the tension bolts therefore create unequal specific pressure along the face surface of the butt. In vital connections, the force of tension of the bolts must be strictly monitored.

Transmittal of a Torque Moment with Fitted Bolts

The transmittal of a torque moment using fitted bolts is accomplished in cases when the moment of friction on the flange face is insufficient for this.

Holes for fitted bolts are manufactured according to a system of holes using reamers which, as a rule, have second class precision and sixth to seventh class fineness.

In designing similar places, it is desirable to stipulate final combined turning of the hole in the parts being connected.

In cases where to provide rigidity of the joint it is necessary to install a larger number of bolts than would be required for reliable transmittal of the torque moment, only part of the bolts used in the connections are made as fitted ones.

When calculating bolts for shear, it is necessary to keep in mind that the torque moment is partially transmitted by the force of friction.

A deficiency of this type of connection is its considerable weight, and in many cases, the non-interchangability of the connecting parts.

Compensators

To eliminate the effect of deformation, takeup clearances, provide normal assembly and operation of connections in the process of operation, it is necessary to provide compensators when designing parts and units.

We will look at the most important types of compensators.

When loading the tail boom of a helicopter with corresponding loads, it bends and twists. During this, a change in the position and distance between the main and intermediate reduction gears takes place. Due to this, the tail transmission shaft will be deformed and loaded with additional forces and moments.

To eliminate this phenomenon, angular compensators in the form of universal joints are introduced (in the first place, the output of the tail transmission shaft from the main reduction gear, and the input into the intermediate reduction gear) (see Fig. 88), as are axial compensators in the form of movable splined shaft connections and sliding supports for the intermediate bearings relative to their clamps. Compensators in the form of short splined sleeves (see Fig. 177) and sleeves with elastic elements are used, allowing angular and axial movement to take place.

To provide setup and assembly operations, it also is necessary to make provisions for compensators in the corresponding places. This type of compensator can include the following:

a) threaded connecting tips on rigid rods (Fig. 179,a) and turnbuckles for cable linkage;

b) introduction of additional inserts. When manufacturing a panelled wing, it is necessary to provide a clearance. When butting the panels together, the clearance is adjusted with inserts. For this purpose, a set of inserts is provided during assembly and adjustment is made "in place" by selecting a proper group from these inserts;

c) fastening parts to framing "in place" after its corresponding installation (for instance, installation of the tail transmission shaft support bearing clamp);

d) introduction of the necessary clearance (see Fig. 179,b);

e) introduction of additional parts -- angle 2 (see Fig. 179,c). The connection of two planes with a third which is perpendicular to them is extremely complex if high precision between these planes is required. Part 1 will always be manufactured according to dimension h with some tolerance. The dimension may be supported to any degree of accuracy by using compensators, for instance, angle fittings. In this case, part 1 is connected with the upper plane by angle fitting 2.

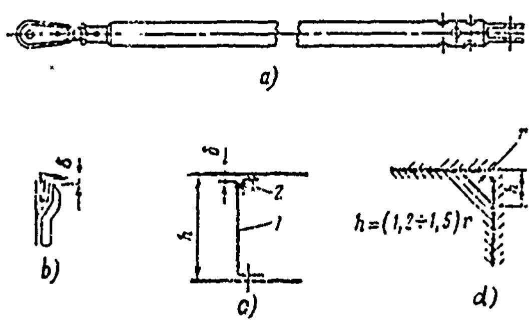

Fig. 179 Compensators:

Key: a) threaded connecting tip on rigid rod, b) the introduction of clearance δ when butting a spar band with an airfoil fastened to the wall, c) introduction of additional part 2, d) bevel on assembled parts

It is necessary to provide the possibility for eliminating slack which can appear during the process of wear in movable connections. The execution of this is possible with springs or other flexible elements (for instance, compensation of ball support wear in the slit hinge of the rotor control assembly) and also by tightening a seal set with the corresponding nut. Dimensions of chamfers on assembled parts are selected with consideration so that with a tight fit, pinching of the parts will not occur (see Fig. 179,d).

Formulation of Drawings for Parts and Joints

A helicopter, like any machine, is composed of separate parts. Assembly of the helicopter from different parts is accomplished in a definite sequence. In correspondence with the technological process of assembly, parts are assembled into units, units are assembled in more complex units, and assemblies are combined in sections and so forth. This sequence is reflected in the drawing numbering system, which the designer is obliged to master and connected with the technological process of assembly. All drawings which are produced on the planned helicopter are subjected to numbering.

We will take a look at how the number of a working drawing is assigned, for which the following definitions are introduced:

1) the part is called a component of the helicopter, manufactured without using assembly operations;

2) separable or permanent connections of parts are called units. Units may be simple, representing a connection of separate parts obtained primarily by technological identical means (for instance, welding, bonding and so forth) and complex, representing connections of several simple units and separate parts. In the majority of cases, the units are connections of parts having a single functional purpose;

3) connections of units and parts having different functional purposes are called assemblies.

Connection of assemblies, units and parts form a section and connection of sections forms the helicopter as a whole. The definitions introduced are conditional to a known degree but are necessary for the proper numbering of the drawings.

In helicopter construction, just as in airplane construction, a six digit system of drawing numbering is used.

The diagramatic structure of the system used is explained by the following table:

B	00	00	00
Number	Group	Subgroup	Part
Number (letter of the alphabet)	Section of helicopter and large assemblies	Assemblies and complex units	Parts and simple units ended with the number "0"

Example: The assembly drawing for the main rotor hub has the designation B2200-00; the assembly drawing of the axial hinge which goes into assembly of the hub in the form of a unit has the designation B2220-00; the assembly drawing of the linkage body which goes into assembly of the axial hinge in the form of a unit has the designation B2221-00; the subassembly of this unit is a simple unit and has the designation B2221-10; the detailed drawing of the linkage which goes into assembly of the body in the form of a part has the designation B2221-11.

The breakdown of the helicopter into groups and subgroups is changed in connection with changes in the technology of its production.

The following drawings go into production: theoretic drawings for the molding shop, assembly and unit assembly drawings for the assembly shops, detailed drawings for the mechanical, casting and other shops. All these drawings are formulated in accordance with the required guidance according to drawing practice. The part on a detailed drawing is given in the scale M1 : 1. For parts with large dimensions, a convenient scale is selected and the required sections, points, cuts and views are given in the "M1 : 1" scale.

In cases where part of a piece having a complex geometric shape and small dimension is machined, this place is marked on the drawing separately in a convenient scale.

For parts having very simple geometric shapes and which are manufactured of semifabricates, separate detailing of the drawing is not required and the dimension required for manufacture of the given part is indicated on the assembly drawing. Such a part is called an "input".

On drawings of parts, assembled units and assemblies, geometric dimensions, fits and tolerances, as well as

sections, views and other information necessary for manufacture of only the given part or for assembly of the corresponding unit or assembly are given. If there is a necessity to show on a drawing the connection of a given part, unit or assembly with other parts to which they are fastened during subsequent assembly or other operations, these parts are drawn with provisional lines and the words "for checking" are written near their assembly dimensions.

In the upper right hand corner of all charts is placed a stamp in which the necessary information for surface machining, heat treatment and covering is placed. If additional information is necessary, it is placed in appendices, and in a stamp opposite the corresponding information title is written: "see appendix". If no information is required during performance of the technological process, a line is drawn through the stamp opposite the corresponding information title.

Specifications for parts, norms and finished products providing the given production process are placed in assembly drawings. In the list of fastening norms are first placed all bolts, then nuts, washers and pins. Normalized parts and semifabricates are designated by corresponding numbers, including the name of the norm, its basic geometric dimensions and the material from which it is manufactured. The necessary information for the part, assembled unit, or assembly depicted on the drawing is given in a stamp located in the lower right hand corner of the drawing.

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